EVALUATION OF MANAGEMENT STRATEGIES

FOR CONTINUOUS FORAGE PRODUCTION

IN CENTRAL OKLAHOMA

By

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Abstract: Forage production in the southern Great Plains is an important aspect of the agricultural industry because forage is used to feed livestock that produce many agricultural products that are consumed. A goal of agricultural production is to improve the output and maintain the profit of products while improving the efficiency of production. One attempt to improve the production of livestock is by increasing the quantity and quality of feed available. This can be done through management strategies employed to produce more forage via crop, nutrient, and soil management. Many research studies in the past have aimed to improve individual aspects of the forage production systems. This dissertation aims to evaluate combinations of summer cropping, tillage, and nutrient management strategies that can be employed by Oklahoma producers to improve forage production quality, quantity, and input efficiency, as well as promote the improvement of the system through precise management and application. We conclude that the use of adequate nutrients applied to summer fallow replacement crops in no-till winter wheat systems can increase production of high-quality forage.

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CHAPTER I

INTRODUCTION

Agricultural producers in the southern Great Plains (SGP) continually strive to increase the profitability and sustainability of production. One method is to utilize the region's moderate climate and graze livestock on winter small grains through fall and early spring. While winter wheat (*Triticum* aestivum) is typically grown for grain, it is also the predominate cereal of choice in the system known as "graze-out" wheat.

On an annual basis in the SGP approximately 30% to 80% of planted wheat is grazed, with 10% to 20% grazed out completely, rather than harvested for grain (Pinchak et al., 1996). Oklahoma reported 1.78 million hectares of wheat planted in 20018, with approximately 10% of that area utilized for graze out purposes (NASS 2018). A survey conducted for the 1995 through 1996 Oklahoma wheat season reported wheat usage as 9% used as graze-out, 41% used as dual-purpose of grazing and grain and, 50% used as grain only (Epplin et al., 1998). In an additional survey also conducted for the 1995 through 1996 wheat season, it was reported that the state averages of fall/winter pasture usage was predominantly cattle, with 67 % of the grazed livestock being stocker cattle and 26 % being cows and replacement heifers (True, 2000). Further investigation reported the state average stocking rates is at or near 0.6 ha $head^{-1}$ for steers, heifers, and cows, the stocking rate increases up to 1 ha $head^{-1}$ for cows with calves.

The panhandle region of the state of the state can have a land requirement as high as 1 ha head^{-1} due to limited seasonal rainfall for sustained intensive grazing. Rate of gain of steers and heifers on graze-out wheat was reported to range from 0.8 to 1.4 kg day^{-1} across the state of Oklahoma (True, 2000).

Due to the amount of wheat utilized for graze-out purposes a large amount of interest has been placed in the agronomic management of a continuous grazing system. Wheat for graze-out, as well as summer forage crops, have been studied extensively, but there is limited literature documenting impacts of intensive forage cropping systems on the forage production, soil properties, and sustainability of the production system. The following chapters study the effects of tillage management, nitrogen applications, and summer fallow replacement strategies on the productivity and sustainability of forage production systems in central Oklahoma.

CHAPTER II

LITERATURE REVIEW

Wheat forage production

Winter wheat is a high quality forage and grain crop that allows producers the opportunity to graze cattle during the winter and early spring months, providing a feed supplement to reduce feed costs or a complete forage diet depending upon the animal class. After the winter months, grazing can be terminated at first hollow stem (Feekes 6) and the crop taken to maturity for grain harvest, or grazing can continue to graze-out in April or early May. Calves grazed on wheat during the winter months have shown increased body weight (BW) and average daily gain (ADG) compared to calves grazing only a native grass pasture (Apple et al., 1993). When steers were grazed on wheat compared to native grass pasture prior to feedlot finishing, the ADG in the feedlot was decreased by 0.13, however initial and final feedlot body weights were greater by 128 kg and 30 kg, respectively (Choat et al., 2003). After the finishing period steers maintained on wheat yielded higher hot carcass weight, dressing percentage and marbling score than those on native grass pasture.

As a wheat crop matures the digestibility decreases rapidly as the plant moves from vegetative production to reproductive stages, the grain head matures and leaves begin to senesce. Fohner (2002) reports the flag leaf (Feekes 9) stage of growth results in the greatest digestibility of the leaves, stems, and heads, of 90%, 75%, and 100%, respectively. For hay production harvest of the crop near the boot stage yields the highest CP and digestibility combination, while the greatest biomass yield is produced when the crop is allowed to mature to the dough stage, however digestibility and CP are much lower. These finding were echoed by Beck et al. (2009), who reported harvested dry matter (DM) to increase 2.25 times when wheat is harvested at dough stage (6.3 Mg ha^{-1}) as compared to boot stage (2.8 Mg ha^{-1}), while the CP was decreased from 15.2% at boot stage to 8.9% at dough stage. Forage hay was shown to increase dry matter intake (DMI) as percent of BW compared to silage, however the harvest maturity had no influence on any feeding or gain parameter for cattle (Beck et al., 2009).

The utilization of wheat as a cool season forage for grazing livestock is a common practice in the southern Great Plains. Much of the wheat is often grown in a continuous wheat system where the field will be planted in the fall and harvested or terminated in the spring, depending on the goal of the crop, and left fallow over the summer. Recent research has focused on the implementation of summer cover crops (forage crops) during the fallow period with the target of improving soil health and increasing land productivity.

Summer Forage Production

Summer forage crops allow the opportunity to increase the forage production and improve management factors such as weed suppression during the warmer summer months when wheat or other cool season forage growth is unavailable. There are many options for summer forages including grasses such as: millets, sorghum, and sudangrass (*Sorghum bicolor*), legumes: alfalfa (*Medicago sativa*) and cowpeas, and forbs such as forage rape (*Brassica napus*) (Caddel & Enis, 2004; Churchill, 1914). Often mixtures of two or more species are utilized to increase the productivity, decrease risk of crop failure, and insure a crop in varying growing conditions.

A study in Oklahoma reported the use of a grass summer forage such as sorghum-sudan, typically yielded the greatest available forage dry matter, followed closely by mixtures containing a grass forage (Horn et al., 2020). The study further reported the use of only pearl millet (*Pennisetum glaucum*) on a sandy soil resulted in low biomass production when compared to the mixture of pearl millet and mung bean. The authors hypothesize this to be due to the loss of N to leaching in a sandy soil when only pearl millet is used (Horn et al., 2020), whereas when planted with a legume such as mung bean the legume could fix nitrogen and increase N availability for the pearl millet. Further analysis of this trial resulted in CP difference, as expected, when legumes are used in comparison to grasses in two of the three site years. Legumes averaged a 16.08% protein concentration which is significantly higher compared to an average of 8.37% protein concentration in the grasses and a 9.05% average protein concentration in the grass-legume mix treatments(Horn et al., 2020). Simulated daily steer gain was also significantly increased with the use of legumes in comparison to the use of grasses for forage production.

Evaluation of warm-season perennial grasses revealed the highest yielding species produce at least one-third of their total biomass in the months of May and June and also typically have the ability to accumulate greater amounts of biomass in successive harvests (Rogers et al., 2012). Differences in quality of the 15 grass species that were evaluated, including varieties of switchgrass (*Panicum virgatum*), lovegrass (*Eragrostis*), bahiagrass (*Paspalum nontatum*), and others, were noted especially in CP levels. Crude protein was observed to be equal or greater than 10.8% for all grasses except "Midland 99" Bermudagrass in 2005 (8.6%) and Alamo switchgrass in 2004 (9.7). The author reported the CP average decreased by 46% from May to August harvests (Rogers et al., 2012).

The production and quality of cowpeas, sorghum, and millet grown for forage production were compared in Louisiana from 1978 to 1980. Dry matter yield of cowpeas has been shown to be significantly lower than that of millet and sorghum by 3.4 Mg ha^{-1} and 1.7 Mg ha^{-1}, respectively, with lower CP content and dry matter digestibility per harvested area (Montgomery, 1982). However, in-vitro analysis resulted in no significant difference in species quality, except for acid insoluble lignin (AIL) and CP content which were both higher for cowpeas by at least 1.63 and 4.4 percent, respectively. The in-vitro analysis results show cowpeas to be of similar quality as sorghum and millet with higher per unit CP content, although the biomass production was of lower quantity. This has led to the integration of cowpeas into summer forage mixtures for planting along with other grassy and pulse species.

Summer forage mixtures may provide a way to increase species diversity, forage production and quality, and reduce the chance of crop loss due to environmental impacts. There are instances where the diversification of planted species does not increase biomass production, such as in three of the four site-years evaluated in Kentucky by Mercier et al. (2021). The authors found the simple mixture of sudangrass, Pearl millet, and Soybean (*Glycine max*) and complex mixture including the species present in the simple mixture as well as, crabgrass (*Digitaria Ciliaris*; *Digitaria sanguinalis*), corn (Zea mays), cowpea, korean lespedeza (*Kummerowia stipulacea*), sunn hemp (*Crotalario juncea*), forage rape (*Brassica napus*) daikon radish (*Raphanus sativus*) and sunflower (*Helianthus annuus*) did not out yield monoculture sudangrass. Management factors such as nutrient management and harvest frequency also impacted the diversity of a forage mixtures and often favored the production of grassy species (Mercier et al., 2021).

Selection of forage species and variety are among the most important decisions that will result in the production of high yielding, high quality forage. The selection of species and variety of forage are not the only decisions that need to be made to produce a high yielding quality forage crop. Better nutrient management may improve the yield of any crop, and for forages quality can also be improved through nutrient management. Specifically, nitrogen (N) management may improve protein in grasses and biomass production and efficiency in all forage species.

Nitrogen for Wheat Forage Production

Nitrogen additions to the soil are important, especially for non-leguminous crop, as N is essential for plant growth, reproduction, and grain production. Nitrogen is utilized for many processes within a plant. For example, plants require N for chlorophyll used in photosynthesis, but the plant also requires N for amino acid production (Leghari et al., 2016). A forage production system is no different from any other cropping system in the requirement of N for biomass production. Nitrogen is utilized by the plant to produce and maintain aboveground biomass. In a forage production system, the crop is harvested for the aboveground biomass and used for feeding livestock, rather than for the grain or fruit. The recommended rate of N for winter wheat forage production in Oklahoma is 30 kg ha^{-1} for every 1 Mg ha^{-1} of biomass yield (Arnall et al., 2018). Just as with any other crop, nitrogen use efficiency (NUE) is one of the most important factors when discussing N applications and management.

Some studies have shown the NUE of forage-only wheat is higher than wheat grown for grain-only purposes. The use efficiency of nitrogen is calculated as the amount of N measured in the plant divided by the amount of N applied from fertilizers, values over 100% removed more N than applied by fertilizers. A study established in Oklahoma reported an average NUE of 76% in forage wheat production, with increases up to 120% NUE when application rates reached 90 kg ha^{-1} N (Thomason et al., 2000). This concept is important since not only does the crop efficiently utilize the N made available through fertilization, but it can also remove N from the soil that could be lost through leaching or volatilization. Thomason et al. (2000) concluded that increased NUE of forage wheat is due to the removal of biomass by grazing prior to flowering stages, which resulted in fewer gaseous N losses normally observed as the plant achieves reproductive stages wheat (Harper et al., 1987; Parton et al., 1988). During protein degradation that occurs as the plant matures, NH_3 can be lost through volatilization from plant residue due to a variety of factors such as temperature, light moisture, and pH (Kanampiu et al., 1997). Increasing NUE of forage wheat is ideal to increase return on investment from fertilizers, utilizing as much applied nutrient as possible.

Although NUE of forage wheat does provide returns on fertilizer applied, it can produce deficiencies in a major quality factor for the forage. Crude protein is known to increase with increasing N application, but has been shown to be lower in high NUE varieties of wheat, while the biomass production was increased (Sharma et al., 2020). The lower NUE wheat varieties had lower biomass production but greater crude protein. Therefore, when trying to achieve the greatest NUE a reasonable compromise between forage yield and forage quality parameters will need to be established.

Different sources of nitrogen can result in differing NUEs dependent on environmental conditions, and methods which they are used and applied. A study evaluating sources of N fertilizer reported an increase in forage biomass and N concentration with increased N rate for all sources except calcium ammonium nitrate, regardless of soil type(Gagnon et al., 2019). Biomass production increased almost linearly with increase in N rate (Gagnon et al., 2019). Although N source can have an influence on the utilization of nitrogen, for forage crops the rate of N required to increase production is not significantly affected by source or soil type, as seen in this study.

Nitrogen management is critical in a wheat production, especially for improving biomass production in wheat used for forage. Research has shown forage wheat has a high N usage resulting in a large draw in nitrogen from the soil system. Due to this large draw in N for high yielding and quality forage, N additions will be needed for any subsequent crop. Therefore, N management likely influences the production of a quality summer forage crop.

Nitrogen for Summer Crop Forage Production

Nitrogen management of all cropping systems is important, especially for more intensive cropping systems such as continuous forage cropping. In an intensive forage cropping system very little biomass is left for microbial breakdown following grazing or hay production, therefore management of nutrients may be required year-round to produce high yielding quality forage. Utilizing a legume crop such as cowpeas or mung beans can ease the reliance on applied N fertilizer. However, due to the short growing season, N additions from legumes may not meet the demands of forage production. Mixtures that contain both grass and legume crops will likely require nutrient management to reduce the amount of competition and produce a quality diverse forage crop.

An evaluation of N management in maize (*Zea mays*), cowpeas, and varying mixtures of the two species showed an increase in forage yield and quality with increasing N application rates from 0 up to 120 kg ha^{-1} for all cropping methods (Asangla & Gohain, 2016). Increased N application rate also resulted in crude protein increases up to 0.58 and 2.81 percent and crude fiber was decreased 5.2 and 0.27 percent for maize and cowpeas, respectively. These increases in dry matter yield were echoed by Mercier et al. (2021), who observed the same increase with increased N application in all but one site-year, where biomass production peaked at 112 kg ha^{-1} due to unforeseen environmental and systemic impacts.

Forage mixture compositions were impacted by the increase of nitrogen rate, where sudangrass and pearl millet were the only species to increase, as a percentage of the mixture, as N rate increased. Sudangrass and pearl millet made up 47 to 87 and 11 to 35 percent of the composition of the mix, respectively. Crabgrass, soybeans, cowpeas and other species that made up less than 20 percent of the composition never responded to an increase in N rate (Mercier et al., 2021).

The N credit is any inorganic N added to the soil from a source other than fertilizers. The N credit of a legume crop has been reported to increase soil nitrate tests (Griffin et al., 2000; N'Dayegamiye et al., 2015), while the value of the increase is largely dependent upon the growing environment. Research in two humid corn production regions reported differing levels of nitrate in the soil following the incorporation of hairy vetch and alfalfa. Griffin et al. (2000) reported soil nitrate levels that exceed the critical threshold of corn production (25 mg NO_3^-N kg^{-1}), while N'Dayegamiye et al. (2015) reported soil nitrate levels to be lower than the critical value, often times less than half of the requirement. When legumes are used in forage systems the addition of nitrate to the soil is much lower as the nitrogen that is fixed is used for production of the biomass and protein and is in large part removed from the system through harvest. The portion left is made up of mostly roots, which has been reported to have an average of 46 kg N ha^{-1} (Griffin et al., 2000).

The utilization of a summer forage crop could increase the total annual forage production of a field but may require a greater level of management, compared to traditional summer fallow. The selection of crop type and N management strategies are both important for the continual production of forage. Although the use of a legume species is typically beneficial for the addition of N through nitrogen fixation, in a forage system the increase in diversity and forage quality outweighs the addition of fixed N. Replacing a warm season fallow period with a summer forage crop inherently impacts the subsequent crop such as by reducing yields, and overall system with increasing total production. This increased production will require increased management of soil health to maintain adequate levels.

Soil Impacts of Continuous Forage Production

The common wheat forage management in the SGP is to graze during the winter and spring months, followed by summer fallow. Research has investigated the use of cover crops in grain systems for many years, to help maintain soil moisture, reduce erosion, and suppress weed production. Recent research investigates the use of cover crops as a forage producing crop as an alternative to a fallow or a crop that doesn't produce an economic return. This summer forage crop could result in similar benefits as a cover crop while also yielding a forage crop to be used for livestock feeding. Other added benefits of fallow replacement summer forage crops are nutrient sequestration and soil chemical and physical improvements.

A study evaluating the effects of replacing fallow with yellow sweet clover (*Meliotus* officinalis), hairy vetch, lentil (*Lens culinaris*), Austrian winter forage pea (*Pisum sativum*), Austrian winter grain pea (*Pisum sativum*), and triticale (*Triticosecale*) cover crops in semi-arid region of Kansas found soil organic carbon concentration increases in the 0 – 7.5 cm depths with the addition of cover crops but no changes beyond this depth (Blanco-Canqui et al., 2013b). Mean diameter of water-stable soil aggregates was also greater with cover crops, although, evaluation nine months after cover crop termination resulted in no significant physical or chemical effects indicating cover crops have a short-lived impact on soil properties (Blanco-Canqui et al., 2013b).

A study established in El Reno, Oklahoma evaluated the impact of summer management practices on soil properties and found that grazed wheat fallow had the highest level of nitrate-N in collected runoff, with an average of 124 kg ha^{-1}, while un-grazed wheat – summer fallow, grazed wheat – summer legume, and un-grazed winter wheat – summer legume all showed less than 5 kg ha^{-1} (Daniel et al., 2006). Summer legumes also resulted in lower sediment yields in collected runoff, which was directly related to the nutrient losses. Summer fallow practices following a grazed winter wheat crop resulted in 71% of the late season precipitation lost due to runoff

(Daniel et al., 2006). These studies reiterate the positive impacts summer crops can have on a soil system, including reduced runoff potential, greater soil nutrient retention, greater soil structure, and even increases in carbon concentrations in the upper 7.5 cm of soil.

In a continuous cropping system, the use of a summer forage crop can create an unwanted draw on the system by removing resources that would be available to the subsequent crops such as nutrients and soil moisture, resulting in an impact to that following crop. However, they can yield benefits for the system as well, such as reducing sediment and nutrient loss and even increase soil moisture levels (Blanco-Canqui et al., 2013b; Blanco-Canqui & Ruis, 2020), when managed properly.

Evaluation of fallow replacement crops effect on stored soil moisture showed that earlier planted crops, triticale and dry pea, retained on average 6 cm more soil moisture, at planting of winter wheat, than later planted millets (Lyon et al., 2007). This increase was attributed to earlier harvest timing for the triticale and dry pea resulting in more opportunity to capture and store precipitation in soil prior to wheat planting. Nielsen et al. (2017) found wheat following triticale had an average 88 mm less available water at wheat planting, than following a fallow period. These results come from the same research sites as Lyon et al. (2007), in the successive years, emphasizing the annual variability in available water. Compared to grain, forage yields are more readily estimated by soil water at planting, and the shorter duration required for forage crops compared to grain crops can result in more stored soil moisture for the subsequent winter wheat crop (Lyon et al., 2007).

A study evaluating the effects of eliminating summer fallow periods showed no winter wheat response to N application, except when following Porso millet (*Panicum miliaceum*) one year (Lyon et al., 2004). Winter wheat yields were shown to not be impacted by the usage of a summer crop in many grain production systems, such as in a wheat-grain sorghum system (Holman et al., 2016). The use of a legume summer crop has shown to increase barley grain and straw yields regardless of fertilizer usage (Abate et al., 2003). Early harvest of forage summer crops increases soil water storage and reduces water harvesting compared to later harvested summer cover crops, leaving more moisture for the subsequent crop (Miller et al., 2018).

The addition of a summer forage crop has potential to improve the system by reducing erosion, increasing soil organic carbon stocks, and can reduce the amount of soil moisture loss through evaporation in hot dry months, compared to a fallow period. While there are major concerns in the SGP regions about intensive forage cropping due to drought conditions and limited rainfall, much of the research from the region and others show a minimal impact to the subsequent crop. Increases in system productivity by the replacement of a fallow period and the reduction of weed seed banks by increased competition are benefits of this management strategy.

Impact of Tillage on Forage Production System

Tillage has been used for many years as an effective method of weed control in the time between cropping seasons. Recently tillage practices have been reduced with the introduction of minimal and no tillage systems in an attempt to improve the soil and reduce erosion and soil moisture losses caused by mechanical disturbances. For continuous forage systems introduction of no or minimal tillage greatly reduces weed control options, especially when multiple species mixes are to be used as summer forage crops. However, reduced tillage could potentially lead to improvements in soil productivity by decreasing soil disturbances and increasing soil moisture content, soil organic matter, soil structure, and reducing erosion.

A 2007 study conducted in Watkinsville, Georgia reported wheat stover yielded a 0.4% increased N concentration under no-till management (1.0% N) compared to conventional tillage (0.6% N) (Franzluebbers & Stuedemann, 2014). Biomass across all cover crop species evaluated increased under conventional tillage versus no-till management, however tillage management had no impact on the stover production of the winter wheat crop. Sij et. al (2016) reported similar results in the rolling plains of Texas with the impact of tillage management having no statistical impact on winter wheat forage yields. Minimal tillage can reduce soil bulk density by up to 13%, compared to conventional tillage in the 0 to 7.5 cm depth, changes may not occurs below the 7.5 cm depth management (Thomas et al., 2008). Thomas et al. (2008) also reported no difference in cumulative nitrate emissions between minimal and conventional tillage strategies in a simulated-grazing triticale study. Winter wheat N concentrations were also not impacted by tillage management (Wiatrak et al., 2004b).

Positive improvements in crop performance have been reported with the introduction of reduced tillage in temperate regions (Krauss et al., 2010). The benefits of introducing a no-till management into a forage production system can be seen by the improvements in soil physical properties and crop production measurements (Blanco-Canqui et al., 2014; Franzluebbers & Stuedemann, 2014; Sij et al., 2016; Thomas et al., 2008) . These improvements led to increases in biomass production and N accumulation (Wiatrak et al., 2004) which leads to increased protein content, as well as benefits of less erosion and soil moisture losses from disturbed soil (Lipiec et al., 2006; Omondi, 2013). Reducing occurrences of tillage events has been reported to improve many crop production systems while also reducing costs of production of crops this may be ideal for continuous forage production systems that can have high associated costs with great risk of loss.

CHAPTER III

IMPACTS OF SUMMER FORAGE CROPS AND TILLAGE MANAGEMENT IN A WINTER WHEAT GRAZE OUT SYSTEM

Abstract

Grazing cattle on winter wheat is a practice that producers have taken advantage of for many years. The majority of wheat grazed is dual purpose, meaning cattle are removed prior to Feekes 6 and wheat is taken to grain production. A significant portion of wheat area is grazed until maturity which is known as a graze-out wheat system. After wheat production the land is typically left fallow and managed for weeds through tillage practices. Recent research interests are to evaluate the introduction of a summer forage as a fallow replacement in a winter wheat grazing system, as well as the use of no-till management to improve the soil health of an intensively cropped system. This study evaluates the management of tillage and summer cropping method in a continuous wheat grazing system. The use of no-till summer forage improved the soil by increasing soil moisture retention and organic matter, while resulting in minor impacts to the winter wheat crop production and cattle gain from the system. This research is focused as a preliminary outlook on the entire system leaving the potential for more focused research on further management decisions of an intensive cropping system.

Introduction

Many producers reduce livestock feeding costs by taking advantage of favorable environmental conditions by grazing livestock on winter wheat in the cooler months and warm season grass pastures in the spring. In the SGP winter wheat grown for grazing is planted in early-September and grazed until mid to late March. Wheat fields are typically fallowed following winter wheat until August, when tillage operations and field preparations for winter wheat are performed. The introduction of summer fallow replacement forage crops would provide increased forage production and available grazing days on a piece of land. Research has evaluated the impacts of summer forage crops on soil chemical parameters (Blanco-Canqui et al., 2013b), erosion management (Daniel et al., 2006) and the effects on the subsequent wheat crop (Unger & Vigil, 1998). Improvements to soil properties are reported to be similar to a traditional cover crop such as weed suppression, reduced evaporation, and reduced soil erosion.

Some forage producers are also interested in shifting from the use of tillage, to a no-tillage approach to improve soil properties and reduce costs. Tillage management in forage production systems have been evaluated (Franzluebbers & Stuedemann, 2014; Sij et al., 2016), and report improvements to the system due to the use of no-till management. However, concerns about the effect on the system following an introduction of summer forages and no-till management are still present. These concerns are relevant, as limited research is available on the long-term influence of both cropping system and tillage management in grazing crop production. The objectives of this study are to evaluate those impacts of summer forage crops and tillage management on continuous winter wheat graze out systems. The authors hypothesize the introduction of summer forages will improve system production while the use of tillage will improve soil properties without a decreasing in system production.

Material and Methods

This study was conducted over five years (2015-2020) including both winter and summer cropping seasons near Ardmore, Oklahoma (34° 13’ 0.75” N, 97° 12’ 30.98” W) on three major soil types: Chickasha loam, Normangee loam, Renfrow silt loam (Figure 2). The trial area was managed as a winter wheat grazing unit for more than 30 years prior to establishment with paddock tillage management strategies in use since the 1990’s.[1] Nitrogen management prior to trial establishment was done using a 112 kg N ha^{-1} application rate of Urea (46-0-0), with applications of 56 kg ha^{-1} in the first two years, and 84 kg ha^{-1} in the final three years of the trial. The trial was established in a winter wheat grazing, summer fallow rotation, as a randomized complete block design with a two-by-two factorial treatment structure with five replications (Figure 1). Treatments factors applied to replicate 2 ha grazing paddocks were the primary factor of crop residue management using either conventional tillage of multiple passes with a disc, or no tillage management system. The secondary factor of summer cropping method of either fallow or a summer crop mixture. Planting dates and variety selection varied with season due to management practices and climate patterns (Table 1). Experimental units were managed using the best management practices for the production system, with applications of herbicides and fungicides, and animals provided with water, supplemental feed, and vaccinations as necessary.

Forage Measurements

Residual biomass was measured using a rising plate meter (Jenquip; Feilding, New Zeland) every seven to fourteen days for both winter and summer pastures, following monthly calibration to ensure accurate data collection. Stocker cattle were used to graze the paddocks at a maximum stocking rate of 2.5 head ha^{-1} which was adjusted as needed upon the available biomass

[1] Exact date of tillage management initiation is unknown to the authors, but can be dated back to the early to mid 1990’s.

for the growing season. Body weight of the cattle was recorded every seven to fourteen days during the grazing periods. Average initial and final BW, stocking rate, grazing period, sex, cattle on date, and cattle off date information can be found in Table 2. In the 2017-2018 winter wheat season cattle did not graze the wheat, therefore the wheat produced was cut for hay production instead.

Soil Measurements

Daily soil moisture and temperature averages were collected using three soil moisture sensors placed at 7.6, 25.4, 61 cm below the soil surface. Data loggers were placed within an exclosures to deter livestock interference and soil sensors were placed 6m outside the exclosure in each paddock for the duration of the study. During the 2015-2016 growing seasons 5TM moisture and temperature sensors (Meter Group; Pullman, WA.) were used at the 7.6 cm depth, and EC5 soil moisture sensors (Meter Group; Pullman, WA.) were used at the 25.4 and 61 cm depths. Starting in the 2016-2017 growing season the 5TM sensors were used at all depth due to data errors from the EC5 sensors. The sensors were in place for the duration of the study except for removal during tillage or planting operations, or sensor failure events. Soil moisture and temperature were collected and logged every five minutes and averaged from midnight to midnight for daily soil data. Daily soil moisture was further grouped by seasonal planting dates, which were selected when sensor reading were first available for all treatments in each seasons, as well as by rainfall events. Rainfall data was collected from a Mesonet weather station (Mesonet; Norman, Ok.) located within 1.5 km (34° 13' 41" N, 97° 12' 5" W). Soil moisture measurements were grouped based upon the daily rainfall into: 0 mm d^{-1}, >0 – 12.5mm d^{-1}, >12.5 – 25 mm d^{-1}, >25 – 50 mm d^{-1}, and >50 mm d^{-1}.

Soil water infiltration rates were measured using a mini disk infiltrometer (Meter Group; Pullman, WA.) set at 2 cm suction at 5 randomly selected locations in each paddock, within a three-day timeframe targeting similar soil moisture contents. Soil infiltration readings were taken in 30 second intervals for a total of 5 minutes. Bulk density measurements were taken prior to each cropping season starting on April 1, 2017 and concluding on April 1, 2020. Each paddock had five samples collected using a 5-cm diameter hammer probe (AMS Inc; American Falls, ID), the samples were then stratified by 0–5 cm, 5–10 cm, and 10–15 cm and oven dried at 65 °C to a constant weight. A 0-15 cm bulk density was calculated by combining the stratified samples. Haney soil heath test (Haney et al., 2018) and standard soil test samples were collected from 12, 2.54-cm cores from each paddock at the beginning of each cropping season (Table 2).

For the Haney soil analysis, soil was dried at 50°C and ground to pass through a 2-mm sieve, then 4 g of soil weighed in to two 50-ml Erlenmeyer flasks, and 40 g of soil is weighed into a 50-ml beaker. The 40 g sample was used for CO_2 respiration through incubation for 24 hours at 24 °C. The CO_2 gas was analyzed using a Li-Cor 840A infrared gas analyzer (Li-COR Biosciences; Lincoln NE). The 4 g sub-samples were extracted by adding 40-ml of de-ionized (DI) water to one and 40-ml H3A to the other, shaken for 10 minutes and centrifuged for 5 minutes, then filtered through a #2 Whatman filter. Both, the 4g H_2O and H3A samples, were analyzed for NO_3-N, NH_4-N, and PO_4-P in a Latchat 8000 flow-injection analyzer (Hach Company; Loveland CO). The H3A extracted samples were also analyzed on an inductive coupled plasma analyzer for phosphorus (P), potassium (K), calcium (Ca), aluminum (Al), and iron (Fe).

Standard soil testing was conducted by drying soil at 65°C for up to 12 hours followed by grinding the soil to pass through a 2-mm sieve. Soil pH was measured using a glass electrode in a 10 ml DI water to 10 g soil solution after 30-minute shaking period. Buffer index (BI) was determined for soils with a pH less than 6.2 by adding 10 ml of Sikora buffer solution, shaking for one hour, and reading again. Nitrate nitrogen (NO_3-N) was extracted from 5 g of soil by adding 25 ml 1 M KCl solution, shaking for 30 minutes, filtering through a #2 Whatman filter and analyzing on a Latchat 8000 flow injection analyzer (Hach Company; Loveland CO). Extraction of P, K, Ca and Mg was accomplished using the Mehlich 3 extraction. This process adds Mehlich 3 extraction solution (0.2 M glacial acetic acid, 0.25 M ammonium nitrate, 0.015 M ammonium fluoride, 0.013 M nitric acid, and 0.001 M ethelyene diamine tetraacetic acid) to 2 g of soil, the mixture was shaken for 5 minutes, and filtered through a #2 Whatman filter and analyzed through an inductive coupled plasma analyzer.

Statistical Analysis

Data analysis was conducted using PROC GLM procedure in SAS software, version 9.4 (SAS Institute Inc., Cary, NC, USA). Mean separation was done using a Fisher's LSD at an alpha of 0.05. Analysis of residual biomass was conducted on the final sampling of each season.

Table 1. Planting date, variety, and rate for each cropping season

Crop	Date	Planting rate & Variety
Wheat (tilled)	9/24/2015	106 kg ha^{-1} Gallagher Wheat + 28 kg ha^{-1} Maton Rye
Wheat (no-till)	9/25/2015	106 kg ha^{-1} Gallagher Wheat + 28 kg ha^{-1} Maton Rye
Summer (no-till)	5/31/2016	34 kg ha^{-1} Mix: Cowpeas, Soybeans, Sunn Hemp, Pearl millet, German millet, Browntop millet, Corn, Buckwheat
Summer (tilled)	6/14/2016	34 kg ha^{-1} Mix: Cowpeas, Soybeans, Sunn Hemp, Pearl millet, German millet, Browntop millet, Corn, Buckwheat
Wheat (no-till)	9/19/2016	135 kg ha^{-1} Gallagher Wheat
Wheat (tilled)	9/19/2016	135 kg ha^{-1} Gallagher Wheat
Summer (no-till)	5/2/2017	34 kg ha^{-1} Mix: Cowpeas, Soybeans, Sunn Hemp, Pearl millet, German millet, Browntop millet, Corn, Buckwheat
Summer (tilled)	6/8/2017	34 kg ha^{-1} Mix: Cowpeas, Soybeans, Sunn Hemp, Pearl millet, German millet, Browntop millet, Corn, Buckwheat
Wheat (tilled)	9/19/2017	135 kg ha^{-1} NF 101 wheat
Wheat (no-till)	9/21/2017	135 kg ha^{-1} NF 101 wheat
Summer (no-till)	5/19/2018	34 kg ha^{-1} Mix: Pearl Millet + Okra + Iron and Clay Cowpeas
Summer (tilled)	6/13/2018	34 kg ha^{-1} Mix: Pearl Millet + Okra + Iron and Clay Cowpeas
Wheat (no-till)	10/3/2018	135 kg ha^{-1} NF 101 wheat
Wheat (tilled)	10/4/2018	135 kg ha^{-1} NF 101 wheat
Summer (no-till)	6/13/2019	34 kg ha^{-1} Mix: Pearl Millet + Okra + Iron and Clay Cowpeas
Summer (tilled)	6/19/2019	34 kg ha^{-1} Mix: Pearl Millet + Okra + Iron and Clay Cowpeas
Wheat (no-till)	9/17/2019	135 kg ha^{-1} NF 201 Triticale
Wheat (tilled)	9/17/2019	135 kg ha^{-1} NF 201 Triticale

*Table 2. Grazing cattle information including the crop grazed, paddock the data represents, stocking rate in head ha^{-1}, Head per paddock, Sex, Date the cattle were allowed on the field, Mean weight (kg) of cattle at release, Date cattle were removed, Mean weight (kg) of cattle at removal, Total days they were allowed to graze, and the Average gain (kg) of those paddocks. Paddocks with * had one head die during grazing period.*

Crop	**Paddock**	**Stocking Rate** *(hd ha^{-1})*	**Head per Paddock** *(Head)*	**Sex**	**Date On**	**Mean Initial BW** *(kg)*	**Date Off**	**Mean Final BW** *(kg)*	**Total Grazing Days**	**Avg. Gain** *(kg)*
Winter Wheat	**All**	1	5	S	12/16/15	535	5/9/2016	966	145	431
Summer forages	**1b, 2b, 3b, 5b, 6a, 7b, 8a, 9a, 10a**	1	5	S	8/3/16	701	8/31/2016	773	28	72
Winter Wheat	**3b, 6a, 7b, 9a, 10a**	1	5	S	11/29/16	578	4/4/2017	917	126	339
Winter Wheat	**1b, 2b, 3a, 4a, 5b, 6b, 7a, 8a, 9b, 10b**	1	5	S	11/29/16	575	4/10/2017	981	132	406
Winter Wheat	**1a, 2a, 4b, 5a, 8b**	1	5	S	11/29/16	564	4/18/2017	1000	140	436
Summer forages	**10a, 9a, 7b, 6a, 3b**	0.8	4	H	7/5/17	781	8/23/2017	855	49	74
Summer forages	**1b, 2b, 4a, 5b, 8a**	0.8	4	H	7/26/17	847	9/5/2017	925	41	78
Winter Wheat	**1a, 1b, 2a, 2b, 3a, 3b, 4a, 5b, 6a, 7a, 7b, 8a, 9b, 10a**	0.4	2	S	2/13/18	554	4/5/2018	706	51	152
Winter Wheat	**4b, 5a, 6b, 9a, 10b**	0.6	3	S	2/13/18	559	4/5/2018	721	51	162
Winter Wheat	**8b**	0.8	4	S	2/13/18	571	4/5/2018	739	51	168
Summer forages	**1b, 2b, 3b, 6a*, 7b*, 9a, 10a**	0.8	4	H	7/19/18	676	8/29/2018	775	41	99
Winter Wheat	**2b, 4a, 5a, 5b, 6a, 7b, 10a**	0.6	3	S	2/14/19	539	5/1/2019	752	76	213
Winter Wheat	**1a, 1b, 2a, 3a, 3b, 4b, 9a, 9b*, 10b**	0.8	4	S	2/14/19	546	5/1/2019	764	76	218
Winter Wheat	**6b, 7a**	1	5	S	2/14/19	551	5/1/2019	757	76	206
Summer forages	**3b, 6a, 7b, 9a, 10a**	1	5	S	7/17/19	557	8/21/2019	626	35	69
Winter Wheat	**All**	1	5	S	12/16/19	551	4/2/2020	835	108	284

Table 3. Soil measurement dates for each of the measured soil parameters.

Date	Infiltration	Bulk density	Standard soil test	Haney soil test
8/5/2015			X	X
4/1/2016	X			
6/10/2016			X	X
8/1/2016	X			
8/16/2016			X	X
4/1/2017	X	X		
4/5/2017				X
5/15/2017			X	
8/1/2017	X			
8/10/2017			X	
8/28/2017		X		
9/28/2017				X
2/27/2018			X	
4/1/2018	X			
4/25/2018		X	X	
8/3/2018		X		
8/21/2018			X	X
8/29/2018	X			
2/4/2019			X	X
5/1/2019		X		
5/14/2019	X			
6/14/2019				X
8/1/2019	X			
8/14/2019		X		
10/1/2019			X	X
2/26/2020			X	
4/1/2020		X		
6/1/2020	X			
6/8/2020			X	X

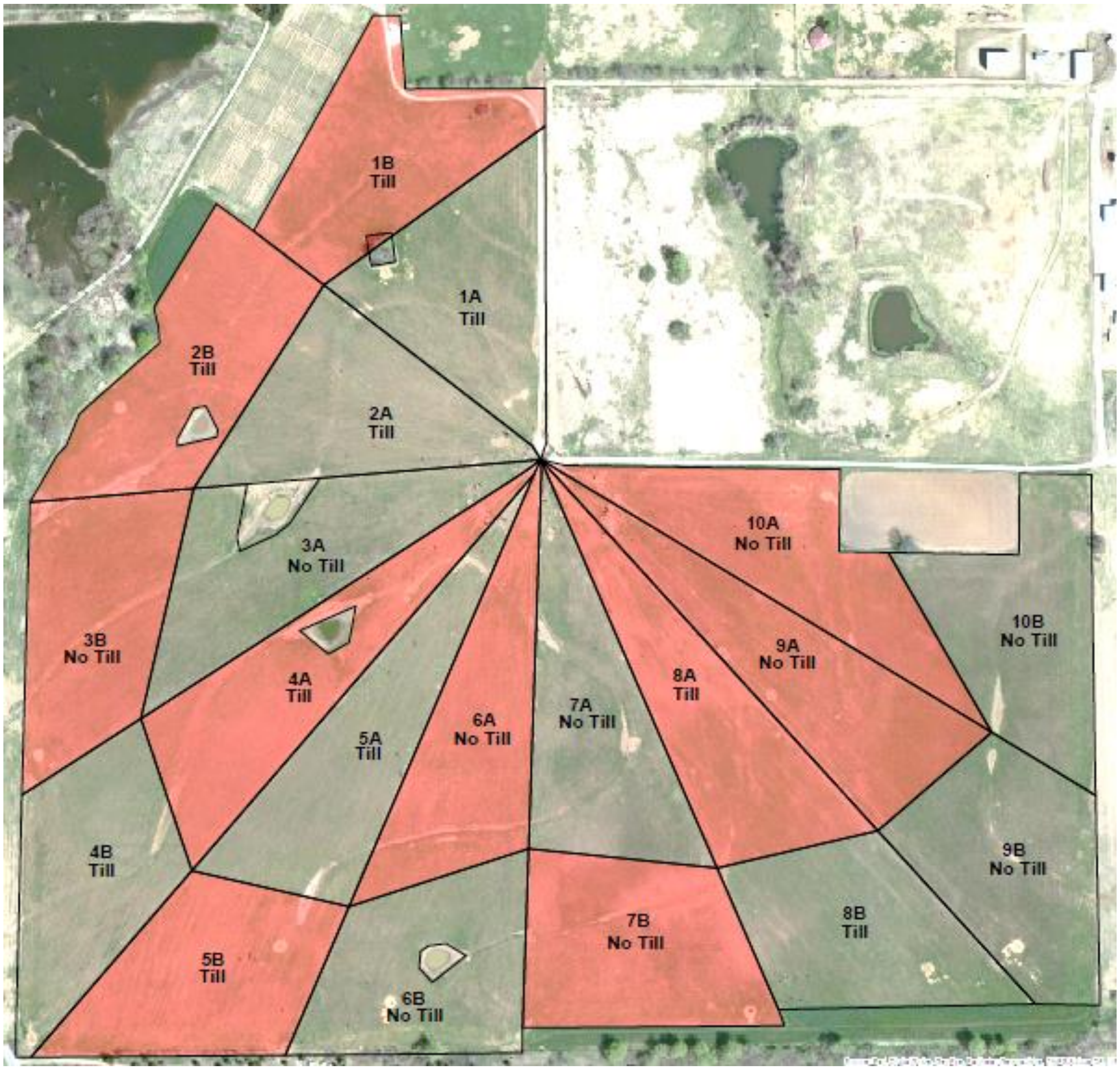

Figure 1. Paddock layout of Noble Research Institute grazing unit (34° 13' 0.75" N, 97° 12' 30.98" W). 20 two-hectare paddocks, managed using conventional disc tillage or no-till (as labeled). Summer forage crops were planted into red-highlighted paddocks.

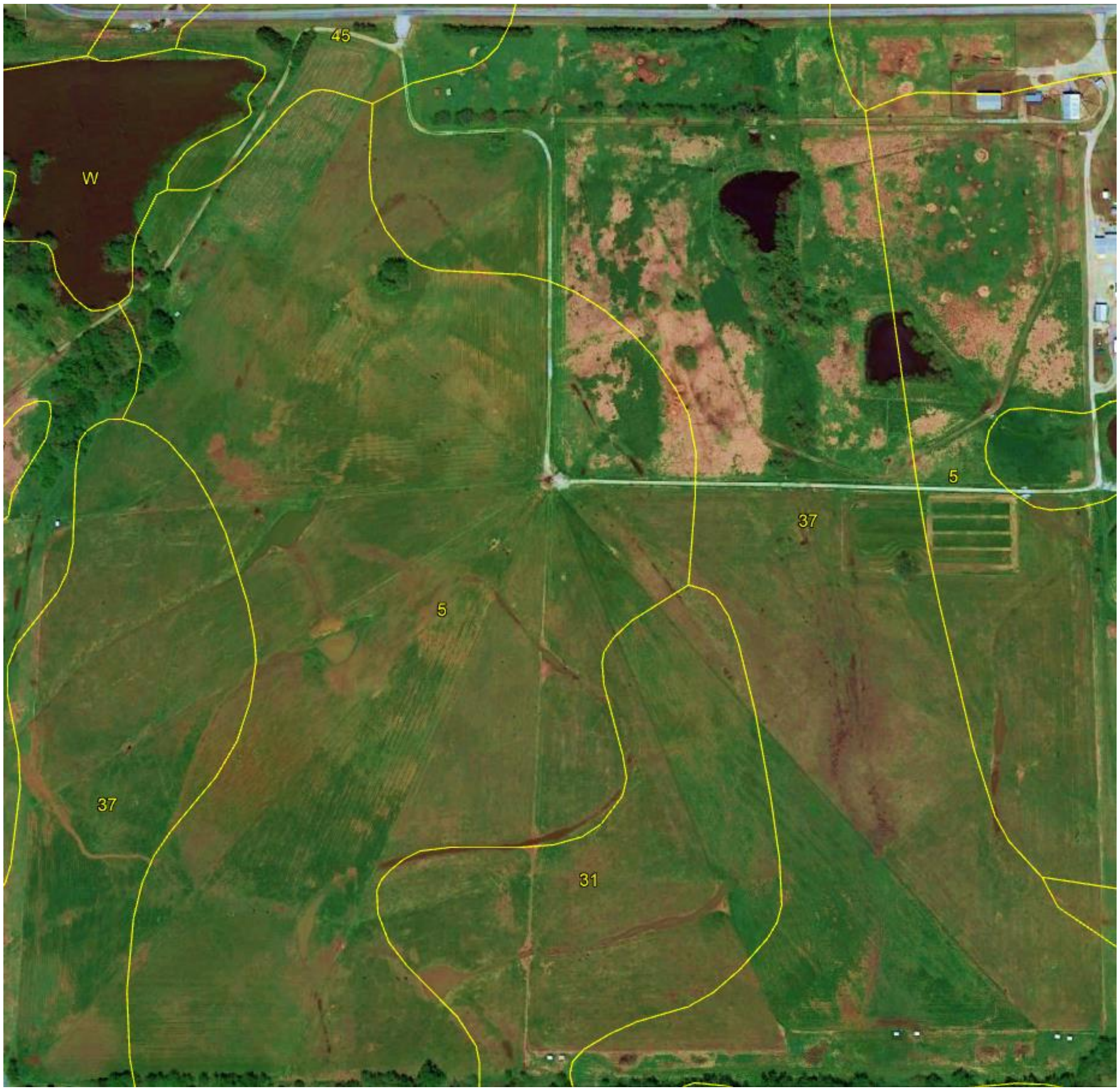

Figure 2. Soil map of Noble Research Institute grazing unit (34° 13’ 0.75” N, 97° 12’ 30.98” W). Soil types are denoted by number: 5 Chickasha loam, 1 to 3 % slope (49% of grazed area), 31 Normangee clay loam 3 to 5% slope (14% of grazed area), and Renfrow silt loam, 1 to 3% slope (37% of grazed area).

Results

Cattle Productivity

Cattle productivity was evaluated based upon total cattle BW gain accumulated per hectare of grazing paddocks in each year. Body weight gain response to treatments were observed in all years of the study as well as system total. Gain produced in 2015-2016, which includes the summer of 2016, was influenced by tillage and summer management independently. The use of tillage decreased total cattle gain from an average of 238 kg ha^{-1} in the no-till paddocks to 181 kg ha^{-1} in tilled paddocks. The use of a summer crop in 2016 resulted in more gain production with 227 kg ha^{-1} of gain compared to the use of a fallow period which produced 189 kg ha^{-1} of cattle gain. The cattle gains of 2016-2017 winter wheat season were influenced unlike the previous year, where tilled paddocks (207 kg ha^{-1}) had greater gain production than in the no-till paddocks (180 kg ha^{-1}) by 27 kg ha^{-1}.

Interaction of tillage and summer crop influenced cattle gains in 2017-2018, where the no-till summer crop (NTSC) treatment had the highest average total gain of 79 kg ha^{-1}, which was greater than all other treatments with an average of 38 kg ha^{-1}. Gain of cattle grazing in 2018-2019 was increased from 57 kg ha^{-1} in tilled paddocks to 89 kg ha^{-1} in no-till paddocks. The final year (2019-2020) of the study, which consisted of only winter wheat grazing, there was an interaction of tillage and summer crop management. In this year of the study the tillage summer crop (TSC) treatment had the lowest average total gain produced of 121 kg ha^{-1}, compared to all other treatments which averaged 137 kg ha^{-1}. At the conclusion of the study total gain production, over the entire time of the study, was also influenced by tillage and summer management. The NTSC yielded the greatest average total gain produced with 757 kg ha^{-1} produced over the five years. This was significantly greater than all other treatments with 653 kg ha^{-1} in NTF, 624 kg ha^{-1} I TSC, and 622 kg ha^{-1} in TF.

Residual Biomass

Interactions between tillage and season ($p < 0.0001$), and between cropping method and season ($p< 0.0001$) were observed for residual biomass production, therefore the treatments were evaluated within each season (Table 4). The interaction between cropping method and season is only applicable for the wheat seasons due to the summer fallow treatments intended lack of summer biomass production. In the first wheat season of this study (2015-2016) the biomass yield was increased from 0.7 Mg ha^{-1} to 1.9 Mg ha^{-1} when no-till management was utilized. This first wheat season was not tested for summer cropping method, as there were no previous summer crop treatments applied. The summer biomass production of 2016 was not influenced by tillage strategy, with a mean yield of 1.2 Mg ha^{-1}.

Winter wheat in 2016-2017 had a 0.6 Mg ha^{-1} increase in yield when tillage (1.1 Mg ha^{-1}) was used compared to no-till (0.5 Mg ha^{-1}), as well as 0.7 Mg ha^{-1} increase when wheat followed a fallow period (1.1 Mg ha^{-1}) compared to when following a summer forage (0.4 Mg ha^{-1}). The summer of 2017 had greater biomass production when summer crops were grown in a conventional till system, with 2.7 Mg ha^{-1}, compared to the no-till system with 2.2 Mg ha^{-1}. In the 2017-2018 wheat season, the impact of tillage was not significant where wheat biomass yields averaged 3.6 Mg ha^{-1}, however, the residual biomass was increased from 3.1 Mg ha^{-1}, when wheat followed a summer forage, to 4.1 Mg ha^{-1} when wheat followed a fallow period. The 2017-2018 wheat season had more biomass measured than all other because winter wheat was not grazed by cattle due to factors outside the scope of this study. The use of summer forage resulted in reduced wheat biomass production in 2017-2018 by 1 Mg ha^{-1}, compared to the fallow period.

Summer residual biomass in 2018 was 0.7 Mg ha^{-1} greater in tillage than a no-till system (1.6 Mg ha^{-1}) (Table 4). Winter wheat residual biomass in 2018-2019 was only influenced by summer management, where the mean residual biomass yield for the tillage treatments 1.2 Mg ha^{-1}. A summer fallow period increased residual biomass of the subsequent wheat by 0.3 Mg ha^{-1}, compared to when wheat followed a summer forage (1.1 Mg ha^{-1}). Neither the summer of 2019 nor the wheat season of 2019-2020 had a response to tillage, with average residual biomass of 1.5 Mg ha^{-1} and 0.5 Mg ha^{-1}, respectively. However, in the final wheat season of 2019-2020 was influenced by summer management, where yields were lower when the wheat crop followed a summer forage (0.3 Mg ha^{-1}) than when wheat followed a fallow period (0.7 Mg ha^{-1}).

Soil Moisture

Planting date soil moisture in the 7.6 cm depth was influenced by the interaction of tillage and summer crop, as well as tillage and season interaction (Table 6). The interaction of tillage and cropping method was not significantly dependent upon season therefore soil moisture levels of all planting dates were averaged and analyzed. When planting occurred in the tilled/fallow (TF) treatment, the soil moisture averaged 0.15 cm^{3} cm^{-3}, which was significantly lower than the other three treatment combinations, which were no different from one another with an average soil moisture of 0.20 cm^3 cm^{-3}. Interaction of tillage management and season was significant in two of the seasons, the first summer (2016) and the final summer (2019). In these two seasons the planting date soil moisture was 0.08 cm^3 cm^{-3} greater under no-till management than in tillage systems. The planting date soil moisture for tillage and no-till management systems were 0.15 cm^3 cm^{-3} and 0.23 cm^3 cm^{-3} in the summer of 2016 and 0.19 cm^3 cm^{-3} 0.27 cm^3 cm^{-3} in the summer of 2019. Although other instances were not significant, the use of no-till typically resulted in higher soil moisture levels. The use of TF reduced planting date soil moisture by 0.05 cm^3 cm^{-3}, compared to TSC or NTF which had 0.26 cm^3 cm^{-3} and 0.25 cm^3 cm^{-3}, respectively (Table 6).

The 60.1 cm depth soil moisture level was influenced by tillage management, summer management and season, independently (Table 6). The use of tillage decreased the average soil moisture levels at 60-cm by 0.05 cm^3 cm^{-3}, compared to the 0.32 cm^3 cm^{-3} level of no-till. While the implementation of a fallow period led to increased soil moisture at the 60.1 cm depth from 0.28 cm^3 cm^{-3} in the forage treatment to 0.31 cm^3 cm^{-3} in the fallow treatments.

When rainfall exceeded 12.5 mm d^{-1} there was no significant difference in mean soil moisture in the 7.6 cm or 25.4 cm depths with mean soil moisture levels of 0.22 cm^3 cm^{-3} and 0.24 cm^3 cm^{-3}, respectively (Table 7). When daily rainfall occurred but was less than 12.5 mm d^{-1} the soil moisture was 0.20 cm^3 cm^{-3} at the 7.6cm depth. There was no significant difference in soil moisture levels at the 25.4 cm depth between the < 0-12.5 mm d^{-1} and <25 – 50 mm d^{-1} groups, which both had 0.23 cm^3 cm^{-3}. While at the 60.1 cm depth soil moisture was highest (0.29 cm^3 cm^{-3}) when rainfall amounts were between

12.5 – 25mm d^{-1} or greater than 50 mm d^{-1}. When rainfall was less than 12.5 mm d^{-1} or between 25 – 50 mm d^{-1}, soil moisture levels were not significantly different at the 60.1 cm depth with an average of 0.287 cm^3 cm^{-3}. Rainfall levels did not show significant interaction effect with the applied treatments; therefore treatment significance was evaluated over the entire data set, regardless of rainfall level.

The interaction of tillage and summer management created significant differences of soil moisture in the 7.6cm and 25.4cm depths over the entirety of the study (Table 8). In the 7.6 cm depth the use of no-till regardless of summer management had the highest soil moisture levels of 0.19 cm^3 cm^{-3}. The use of TSC and TF had the lowest soil moisture levels in the 7.6 cm depth of 0.18 cm^3 cm^{-3} and 0.17 cm^3 cm^{-3}, respectively. The soil moisture levels of the 25.4 cm depth were highest for the TSC treatment at 0.24 cm^3 cm^{-3}, followed by NTF (0.23 cm^3 cm^{-3}), NTSC (0.22 cm^3 cm^{-3}) and, lowest with TSC at 0.19 cm^3 cm^{-3}. The 60.1 cm soil moisture depth was impacted by tillage and summer management independently over the entirety of the study period. Soil moisture was increased due to no-till (0.28 cm^3 cm^{-3}), compared to tillage (0.26cm^3 cm^{-3}). While the introduction of a summer forage into the system led to increased soil moisture as well with an average soil moisture of 0.28 cm^3 cm^{-3}, compared to the 0.27 cm^3 cm^{-3} when a fallow period was used.

Soil Physical Properties

Soil infiltration, which is a measurement of the rate water infiltrates the soil profile, was measured towards the end of each growing season (Table 9). Analysis results showed the soil infiltration was influenced by summer management over the entire study, and the interaction of measurement date and tillage. For summer forage analysis the data was averaged over the entirety of the study and resulted in the use of a summer fallow period yielding higher water infiltration rates. Where the summer forage treatment had an average soil infiltration rate of 1.4 cm $hour^{-1}$, while the fallow period treatment averaged 1.8 cm $hour^{-1}$. Tillage by date interaction resulted in significant differences in tillage at the first soil infiltration reading at the conclusion of the 2015-2016 wheat season, and the conclusion of the 2017 summer season. In the 2015-2016 wheat season the infiltration was increased using tillage from 0.7 cm $hour^{-1}$ in no-till to 1.5 cm $hour^{-1}$ in the tillage treatment. The 2017 summer season showed similar increases in the infiltration of water with tillage having an infiltration rate of 1.9 cm $hour^{-1}$ and no-till rate of 1.6 cm $hour^{-1}$.

Bulk density samples were collected at the same time as soil infiltration samples at stratified depths of 0-5 cm, 5 cm – 10 cm, 10 cm – 15, and these depths were summed to have a 0 – 15 cm bulk density. No treatment effects on mean bulk density were observed for any stratified depth, with 1.53 g cm^{-3}, 1.59 g cm^{-3}, and 1.62 g cm^{-3}, for the 0 – 5 cm, 5 - 10 cm and 10 – 15 cm depths, respectively. The bulk density for the entire 15 cm depth was significantly impacted by tillage management, summer management, and sampling date, therefore analysis was conducted between treatments at each sampling date (Table 10). Significant response to tillage management and summer cropping method was observed at the conclusion of the 2017 and 2018 summer only. At the conclusion of the 2017 summer, the TF had the lowest bulk density of 1.32 g cm^{-3}, followed by TSC with 1.54 g cm^{-3}, NTSC with 1.61 g cm^{-3}, and highest with NTF at 1.66 g cm^{-3}. Similar to 2017, the 2018 summer saw decreased soil bulk density with the use of tillage regardless of summer management with an average bulk density of 1.37 g cm^{-3}, which is lower than the NTSC and NTF by 0.15 g cm^{-3}, and 0.26 g cm^{-3}, respectively.

Soil Test Analysis

The soil tests conducted were standard soil testing procedures used by commercial soils laboratories and the Haney soil test for soil health. A total of 50 variables, between the two soil tests, were analyzed. Significant responses to treatment and date were found for 48 of them (App. Table 1). This data was subset by initial and final sampling dates and analyzed for differences (Table 11). Sampling at trial initiation documented differences in water extractable total N ($H_2O\_N_T$), water extractable organic N ($H_2O\_N_O$), H3A extractable nitrate ($H3A\_NO_3$), H3A extractable inorganic N ($H3A\_N_I$), traditional N and, water extractable carbon (H_2O_C), across the four treatments. These significant differences can be attributed to spatial variability of the soil which has been well documented (Kariuki et al., 2009; Solie et al., 1999; West et al., 1989).

The NTSC treatment paddocks had the highest soil test values for all N measurements (Table 11) and values which were statistically greater than those for the TF and TSC treatments. While the NTF paddocks had numerically higher N and OC values than the tilled treatments, it was not always significantly greater. The H_2O_C in NTSC was statistically greater than the TSC area not but not greater than NTF or TF. Again, as these measurements were collected prior to treatment establishment the differences must be caused by prior management, for which records were not available, or by natural soil variability. By the conclusion of the project only three of the 50 measured soil variables had statistically significant differences, none of which were related to the differences found at trial initiation. The three soil test variables with noted differences are standard soil test organic matter (OM_{Std}), Haney test soluble salts (SS_H), and H3A_Fe. For OM_{Std}, as expected the NTSC had significantly greater OM concentration than TSC and TF at 1.58, 1.26, 1.14% OM respectively. However, NTF (1.44%) was not statistically different from the TSC treatment. Decreases in OM_{std} were observed over the time of the study (App. Table 3; App. Figure 1), however the decrease from initiation to conclusion of the trial was not different between treatments ($p = 0.8452$) and averaged -0.7%. The SS_H values showed the same numeric trend as OM_{Std}, however, the only significance difference was that NTSC was greater than all other treatments. Interestingly the H3A_Fe results showed differences across treatments with the TF having greater values than NTSC and NTF.

Discussion

The results of this study were consistent both above and below ground. At initiation of the trial, soil chemical analysis results showed significant spatial variability of N and C, where the no-till treatments had higher concentrations than present in the conventionally tilled treatments. Spatial variation of soil N have been reported in several previous studies (Kariuki et al., 2009; Solie et al., 1999; West et al., 1989), and can be attributed to previous management of the study, where the tillage treatments have been managed long-term prior to the study.

Reductions of residual biomass in the first year 2015-2016 were a result of tillage treatments and reflect the results of other studies that found increases in wheat forage biomass when no-till management was used (Bowman et al., 2008; Bushong & Peeper, 2004; Wiatrak et al., 2004b). The reduced biomass led to decrease gain of cattle grazing the tilled wheat paddocks in 2015-2016, as well. At this time of the study, collection of soil moisture measurements had not yet been initiated however, final soil water infiltration rates were increased due to the use of tillage which could have resulted in more soil moisture availability and increased yields. Increased soil infiltration rates in tilled cropping systems have been shown in previous research (Blanco-Canqui et al., 2010; Lipiec et al., 2006), however (Bharati et al., 2002) reported lower infiltration rates in conventional tilled soybeans, compared to no-till.

The planting date soil moisture levels in the 2016 summer showed tillage treatments to be 0.08 cm^3 cm^{-3} lower, on average, than in the no-till treatments. Increased soil moisture levels due to the use of no-tillage has been reported by several previous studies and over a variation of climates (Blevins et al., 1983; De Vita et al., 2007; Omondi, 2013). However, in Oklahoma winter wheat grain production Patrignani et al. (2012) found similar plant available water levels between no-till and conventionally tilled systems. Soil moisture levels were not significantly impacted by treatment at the planting of 2016-2017 wheat; however, there was greater residual biomass by 0.5 Mg ha^{-1} when tillage was used and by 0.7 Mg ha^{-1}, when following a fallow period. Lyon et al. (2004) and Nielsen et al. (2017) both reported increases in biomass production when forage crops followed a summer fallow period. Similar to residual biomass the gain of cattle in 2016-2017 was also higher in the tilled paddocks compared to no-till. The decrease in gain and residual biomass could be attributed to lower biomass availability throughout the season in the no-till paddocks. However, Nyamukanza et al. (2008) reports poor or negative correlation between dry matter and body weight gain of grazing cattle.

Summer 2017 residual biomass was greater in tillage by 0.5 Mg ha^{-1}, and could be linked to the increased gain of cattle in the 2016-2017 season. Soil water infiltration in the 2017 summer was also greater in the tilled paddocks, while bulk density was lowest for the TF treatments compared to all other treatments. When a forage was used, the TSC had lower bulk density than NTSC by 0.07 g cm^{-3}, while both summer forage treatments had lower bulk densities than NTF.

Planting date soil moisture in the 2017-2018 was lower than any other planting date in the study at 0.22 cm^3 cm^{-3}. The winter wheat was grazed for a short period, and biomass was cut for hay at the conclusion of the season. 2017-2018 winter wheat was only influenced the use of a summer fallow period that increased biomass production. Soil physical parameters were not responsive to any treatment, which authors associate to the choice to hay rather than graze-out, as it has been reported that cattle grazing increases bulk density (Daniel et al., 2002; Northup & Daniel, 2010).

Residual biomass in summer of 2018 was greater with the use of tillage by 0.6 Mg ha^{-1}, however cattle gain of the 2017-2018 year was greatest in the NTSC treatment, which includes both summer and winter grazed cattle. Bulk density of summer 2018 was reduced with the use of tillage, which is similar to other instances in this study as well as previous studies that reported tillage reducing bulk densities (Dam et al., 2005; Lampurlanés & Cantero-Martínez, 2003; Unger & Jones, 1998). Winter wheat in 2018-2019 had one of the lowest planting date soil moisture levels of 0.21 cm^3 cm^{-3} at 7.6-cm depth and 0.26 cm^3 cm^{-3} at 60.1-cm depth. Temporal differences in soil moisture, such as planting dates throughout this study, are expected and have been reported in Oklahoma previously by Illston et al. (2004). Unlike previous years, tillage impacts to biomass are not observed in the 2018-2019, however, there was an influence of summer cropping method. The use of a fallow period resulted in 0.3 Mg ha^{-1} more residual biomass after cattle grazing, compared to when wheat followed a summer crop. The summer of 2019 had more soil moisture at planting in the no-till treatments by 0.06 cm^{3} cm^{-3}; however, no other responses were observed. Cattle gains of 2018-2019 were influenced by tillage with increased body weight gain in the no-till treatments.

Residual biomass was 1.5 Mg ha^{-1}, and cattle were only grazed on the NTSC treatment due to factors outside the scope of this study. Winter wheat residual biomass in 2019-2020 was 0.5 Mg ha^{-1} greater if a summer fallow period preceded the wheat, similar to the previous wheat crops and other studies (Blanco-Canqui et al., 2013b; Holman et al., 2016; Horn et al., 2021). Tillage treatment affects on biomass were reduced to a level of non-significance over the time of the study similar previous studies that have found improvement or no difference in wheat production under no-till (Franzluebbers & Stuedemann, 2014; Sij et al., 2016). Cattle gain was found to be lowest when cattle grazed wheat following a fallow period in a tilled system. The responses of cattle gain to tillage system found in this study are contrary to other study in the SGP that observed no differences in cattle live weight gain between tillage management (Franzluebbers & Stuedemann, 2004, 2014).

Soil measurements conducted at the conclusion of the study show differences in three of 50 variables, which are different variables found to be different at the initiation of the study. The NTSC treatment yielded the highest OM level of 1.58% which was greater numerically than all other treatments, which is similar to the initiation of the study. This result reflects the finding of previous studies such as Reicosky et al. (1995), who reports losses of up to 110 kg ha^{-1} yr^{-1} of organic matter when it is incorporated. While the use of NTSC increased the soluble salts measured by the Haney test, similar the finding of tillage reducing the SS concentration of rice fields (Wilson et al., 2000). The increase in Fe concentration measured by the Haney test due to the use of TF, are similar to the finding of a study by Lavado et al. (1999), however they report the cause of the increased concentration cannot always be explained as a function of changes in the soil, which was reported by Ferguson (1990). Increases in Fe could be attributed to the reductions observed in OM over the time of the study, by releasing Fe from the exchange sites found on during microbial breakdown. Soil moisture at the study conclusion was one of the highest with 0.25 cm^3 cm^{-3} at 7.6 cm and 0.35cm^3 cm^{-3} at 60.1 cm. No other soil physical measurement was significantly different between treatments at the conclusion of the study.

Conclusion

The objectives of this study were to evaluate the impact of a summer fallow replacement crop, and tillage management on a continuous wheat graze out system. Soil chemical properties evaluated by both the Haney and standards soil tests showed to vary spatially at the initiation of the trial. At the conclusion of the trial there was response in three of the fifty measured soil chemical properties, where OM was observed to be higher in the NTSC treatment followed by the NTF and TSC treatments. Although the OM values were higher there were decreases observed over-time of the study. The Haney test reported greater soluble salt content in that treatment as well, although these values are lower than problematic levels (2600 ppm) increasing soluble salt levels should be observed to prevent future problems such as salinity.

The response of soil physical properties to the replacement of a summer fallow period showed to be minimal, however soil water infiltration was decreased using a forage over the period of the whole trial. The use of tillage increased the soil water infiltration following the first wheat season and the 2017 summer, while all other seasons showed no significant differences between tillage treatments. Soil bulk density was reduced by tillage, numerically and significantly, in both instances where response was observed. Tillage typically led to decreased soil moisture at all depths, while the 7.6 cm and 25.4 cm depths were decreased by the interaction of tillage management and summer cropping method. Over the study period both depths resulted in the lowest soil moisture content in the TF treatment, while at the 60.1 cm depth the use of a summer forage resulted in soil moisture savings over the period of the entire study.

Winter wheat residual biomass was decreased with the replacement of a summer fallow period by a summer forage, in every wheat season that followed initiation of summer forage. Results showed low wheat yields in the tilled paddocks following the implementation of the study, however as time went on tillage improved wheat production. In the 2018-2019 wheat season and beyond the influence of tillage was no longer evident study resulting in no difference between tillage treatments in wheat or summer cropping seasons. Similar resulted were observed for cattle, where in the first year (2015-2016) gain of cattle was decreased due to tillage. In 2016-2017 residual wheat biomass was decreased when wheat followed a NTSC in 2016-2017, and in the following summer it was decreased by the use of tillage. However cattle gains were greater in the tillage treatments. The only other influential factor was summer cropping method in the final wheat seasons (2019-2020). This season gain of cattle was decreased when tilled wheat followed a summer fallow period, compared to when wheat followed any other treatment.

This research found the implementation of a summer forge also provided more grazing opportunities, resulting in more total cattle gain production over the term of the study. The summer cover crop also led to higher soil quality parameters such as organic matter, which results in greater carbon sequestration, and soil moisture levels with greater infiltration and retention than the other treatments in the study. The use historical use of tillage in this study improved many factors early in the system, however these improvements were lost through the duration of the study and no different from no-till after three to four years. Tillage resulted in lower soil moisture throughout the study, which in a drought susceptible climate has the potential to decrease forage production. In this system factors which decrease crop production in turn are detrimental to the livestock grazing.

This work indicates the use of a summer forage crops in replacement of summer fallow increases the total productivity of cattle grazing in the system, with limited impacts to the soil health of the system. This study also indicates although the use of tillage improved some parameters early in the study, overtime tillage was not different from no-till and would only result in a greater cost to producers in field management. Further work is needed to evaluate the operational economics of tillage and summer cropping management, as well as to evaluate species mix performance, to provide the best option for producers economically.

Table 4. Average total cattle weight gain per hectare (kg ha^{-1}) of cattle grazing paddocks each year of the study and total system. P-value reported for significant response within season. Treatments ar no-till summer forage crop (NTSC), no-till summer fallow (NTF), tilled summer forage crop (TSC), tilled summer fallow (TF).

Treatment	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	Total
	kg ha^{-1}					
NTSC	260.9	180.4	79.2	92.5	143.6	756.5
NTF	208.5	180.2	31.2	85.2	147.5	652.6
TSC	192.6	216.3	40.8	53.5	121.0	624.3
TF	169.8	197.5	40.9	60.9	152.4	621.5
Tillage	<0.0001	0.0003	0.026	0.0115	0.087	0.0003
Crop	0.0007	ns	0.008	ns	0.0022	0.0086
Interaction	ns	ns	0.0008	ns	0.0122	0.0119

Table 5. Residual biomass of grazing paddocks within each season of the study. P-value reported for significant response with-in season. Treatments are no-till summer forage crop (NTSC), no-till summer fallow (NTF), tilled summer forage crop (TSC), tilled fallow (TF).

Treatment	5/10/2016	8/31/2016	4/13/2017	8/25/2017	4/4/2018	8/30/2018	5/6/2019	8/16/2019	4/2/2020
	Mg ha^{-1}								
NTSC	2.0	1.1	0.3	2.2	2.9	1.6	1.0	1.3	0.4
NTF	1.8	--	0.6	--	4.0	--	1.2	--	0.6
TSC	0.8	1.3	0.5	2.7	3.3	2.2	1.1	1.6	0.2
TF	0.6	--	1.6	--	4.3	--	1.5	--	0.8
Tillage	0.0017	0.1222	0.002	0.0498	0.0796	0.002	0.1017	0.2044	0.7967
Crop	ns	ns	0.0012	ns	<.0001	ns	0.0286	ns	0.0005
Interaction	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 6. Average soil moisture level ($cm^3\ cm^{-3}$) at planting within treatment over the period of the study. Letter coding with in column represents significant differences. Treatments are no-till summer forage crop (NTSC), no-till summer fallow (NTF), tilled summer forage crop (TSC), tilled fallow (TF).

Treatment	**7.6 cm Soil Moisture**		**25.4 cm Soil Moisture**		**60.1 cm Soil Moisture[1]**	
			($cm^3\ cm^{-3}$)			
NTSC	0.20	a	0.24	ab	0.24	aA
NTF	0.21	a	0.25	a	0.25	aB
TSC	0.19	a	0.26	a	0.26	bA
TF	0.15	b	0.21	b	0.21	bB

[1] lower case letter coding represents tillage significance
uppercase represents summer crop significance

Table 7. Average soil moisture level ($cm^3\ cm^{-3}$) across the study period when rainfall occurred at 0 mm d^{-1}, 0-12 mm d^{-1}, 12-25 mm d^{-1}, 25-50 mm d^{-1}, and greater than 50 mm d^{-1}. Letter coding with in column represents significant differences.

Rainfall	**7.6 cm Soil Moisture**		**25.4 cm Soil Moisture**		**60.1 cm Soil Moisture**	
mm d^{-1}	-----------------		*$cm^3\ cm^{-3}$*		-----------------	
0	0.17	**c**	0.22	**c**	0.27	**c**
0 - 12	0.20	**b**	0.23	**b**	0.29	**b**
12 - 25	0.22	**a**	0.24	**a**	0.29	**a**
25 - 50	0.22	**a**	0.23	**ab**	0.28	**b**
≥50	0.23	**a**	0.25	**a**	0.29	**ab**

Table 8. Average soil moisture level ($cm^3\ cm^{-3}$) at planting within tillage treatment over the period of the study. P-value reported for significant response with-in season.

Treatment	**2016 Summer**	**2016-2017 Wheat**	**2017 Summer**	**2017-2018 Wheat**	**2018 Summer**	**2018-2019 Wheat**	**2019 Summer**	**2019-2020 Wheat**	**2020 Final**
No-till	0.23	0.17	0.17	0.19	0.17	0.17	0.27	0.23	0.24
Tillage	0.15	0.16	0.16	0.18	0.12	0.15	0.18	0.18	0.26
P-value	0.0001	0.8158	0.8882	0.4201	0.0813	0.1924	0.0181	0.0809	0.5219

Table 9. Average soil water infiltration rate (mm h^{-1}) at the conclusion of each season within tillage treatment over the period of the study. P-value reported for significant response with-in season.

	4/1/2016	8/1/2016	4/1/2017	8/1/2017	4/1/2018	8/29/2018	5/14/2019	8/1/2019	6/1/2020
No-till	0.66	2.02	0.98	1.57	1.55	2.46	0.82	1.50	1.24
Tillage	1.52	1.73	0.84	1.89	1.22	3.64	1.68	1.58	1.65
P-value	0.0007	0.442	0.2396	0.0352	0.2494	0.5606	0.3273	0.8387	0.0994

Table 10. Average soil bulk density (g cm^{-3}) at the conclusion of each season within tillage treatment over the period of the study. . Letter coding with in column represents significant differences. Treatments are no-till summer forage crop (NTSC), no-till summer fallow (NTF), tilled summer forage crop (TSC), tilled fallow (TF).

Treatment	4/1/2017	8/28/2017		4/25/2018	8/3/2018		5/1/2019	8/14/2019	4/1/2020
	------------------- *g cm^{-3}* -------------------								
NTSC	1.61	1.61	**c**	1.65	1.52	**b**	1.64	1.62	1.65
NTF	1.63	1.66	**d**	1.69	1.64	**c**	1.66	1.62	1.63
TSC	1.64	1.54	**b**	1.58	1.39	**a**	1.55	1.47	1.62
TF	1.65	1.32	**a**	1.56	1.35	**a**	1.61	1.52	1.61

Table 11. Mean value for measured soil parameters that were significantly different by treatment at trial initiation and conclusion. Letter coding represents signficant differences within variable within sample period. Treatments are no-till summer forage crop (NTSC), no-till summer fallow (NTF), tilled summer forage crop (TSC), tilled fallow (TF).

Treatment	**OM_{std} (%)**	**SS_H (kg ha^{-1})**	**$H_2O\_N_T$ (kg ha^{-1})**	**$H_2O\_N_O$ (kg ha^{-1})**	**H_2O_C (kg ha^{-1})**	**$H3A\_NO_3$ (kg ha^{-1})**	**$H3A\_NH_4$ (kg ha^{-1})**	**$H3A\_N_I$ (kg ha^{-1})**	**H3A_Fe (kg ha^{-1})**	**$N_{Traditional}$ (kg ha^{-1})**
	Initial									
NTSC	2.24	0.37	43.4 **a**	27.6 **a**	271 **a**	14.6 **a**	1.59	16.2 **a**	524	29.1 **a**
NTF	2.16	0.23	40.0 **a**	26.3 **ab**	258 **ab**	12.6 **ab**	1.46	14.1 **ab**	534	25.2 **ab**
TSC	1.94	0.20	29.6 **b**	22.9 **c**	229 **b**	5.6 **bc**	1.14	6.8 **bc**	435	11.3 **bc**
TF	1.90	0.24	28.4 **b**	23.4 **cb**	244 **ab**	3.8 **c**	0.99	4.8 **c**	431	7.6 **c**
	Final									
NTSC	1.58 **a**	0.42 **a**	27.1	17.2	276	6.3	5.6	11.8	171 **b**	11.2
NTF	1.44 **ab**	0.14 **b**	27.3	17.4	279	6.4	5.5	11.9	169 **b**	11.6
TSC	1.26 **cb**	0.10 **b**	24.9	16.8	261	5.0	4.4	9.3	187 **ab**	9.0
TF	1.14 **c**	0.11 **b**	28.3	19.7	267	6.3	5.2	11.4	221 **a**	11.2

CHAPTER IV

EVALUATION OF MANAGEMENT SYSTEMS FOR CONTINUOUS WINTER WHEAT FORAGE PRODUCTION

Abstract

While much of the wheat area in the SGP is used for grain and/or dual-purpose wheat, a portion is planted only for grazing cattle. This area allow for the grazing of cattle during the winter and spring months, and during summer months cattle are typically moved to a warm season grass pasture for grazing. The use of cropland for forage production during summer months could allow for increased profitability and less stress of pasture lands. However, intensive cropping systems, such as continuous forage production systems require proper management. Many research studies have evaluated the management of forage crops from individual aspects such as nutrient management or fallow replacement management. This study aims to evaluate the management of both nutrient and summer forage management in a continuous forage production system. In this research, split application to winter wheat and application of N in the summer months improves system production and quality, while the use of a summer cowpea crop improves the overall biomass production. Determining optimum N rate, N timing, and summer crop species in future research is necessary for refinement and continued improvement of a continuous forage production system.

Introduction

Agriculture producers often try to utilize every opportunity available to increase productivity of their land and resources. A continuous forage production approach, by utilizing multiple forage cropping seasons on one area of land, may give livestock producers the opportunity to increase productivity and profitability of their operations. The common practice of utilizing winter wheat for forage production with the addition of planting forage crops in the summer months, rather than using a traditional fallow period, is one approach that could increase production. However, a continuous cropping approach such as the one described can increase demand of nutrients which will require management strategies to mitigate crop stress. The management of nutrients is important for any cropping system, while the increased stress on the system by continuous forage production will require more intensive management, especially for N. The management of N is another way producers can increase the productivity and profitability of an area of land. It could also reduce the demand on the system caused by continuous forage production.

The management of nutrients, especially N, for wheat forage production have been studied for many years such as by Sharma et al. (2020), Naveed et al. (2013), and Thomason et al. (2000). Similarly many studies have focused the use of summer forage crops to replace traditional summer fallow periods (Horn et al., 2021; Mercier et al., 2021; Montgomery, 1982; Rogers et al., 2012). Management of N in summer forage crops has also been the focus of many researchers (Mercier et al., 2021). However, few studies have focused on the management of summer forage crops and N for winter wheat and summer crops in the same continuous forage production system. Therefore, the objectives of this study are to evaluate nitrogen management strategies for improving continuous forage production, and to evaluate impacts of summer fallow replacement crops in continuous forage production system.

Materials and Methods

Study Area

This trial was conducted across three locations from fall 2018 to summer 2021 covering both summer and winter cropping seasons every year. The trial was established as a three by four by two factorial with four replicates at two locations: South Central Research and Extension Center in Chickasha, Oklahoma, and Lake Carl Blackwell (LCB) near Stillwater, Oklahoma. The primary factor was wheat nitrogen application with three treatments 67 kg N ha^{-1} at pre-plant, 135 kg N ha $^{-1}$ at pre-plant, and a split application of 67 kg N ha^{-1} at pre-plant followed by a top-dress application of 67 kg N ha $^{-1}$. Top-dress wheat N applications occurred following spring green-up, or first harvest in years of limited winter wheat growth. The secondary factor was summer management with four treatments including summer fallow, cowpea (*Vigna unguiculata*) planted at 67 kg seed ha $^{-1}$, pearl millet (*Pennisetu, glaucum*) planted at 22.42 kg seed ha $^{-1}$, and a three to one ratio, by weight, cowpea and pearl millet mixture with 34 kg cowpea ha^{-1} and 11.2 kg pearl millet ha^{-1} within each of the primary factors. A tertiary factor of summer nitrogen application was applied at 0 or 34 kg N ha $^{-1}$ within each of the secondary factors.

Winter wheat was planted using the Gallagher variety developed by Oklahoma State University, at 145 kg $ha^{-1}$and 135 kg ha^{-1} at Chickasha and Lake Carl Blackwell, respectively. Winter wheat nitrogen was applied as urea 46% N (CH_4N_2O) for pre-plant and top-dress applications, summer crop nitrogen applications used liquid urea-ammonium nitrate 28% N (CH_4N_2O-NH_4NO_3). Field management was conducted to reflect tradition rainfed continuous forage production methods. Planting and fertilization dates for each season at each location can be found in Table 4.

Soil Analysis

Pre-plant 0-15 cm depth soil samples were taken for nutrient analysis from each sub plot prior to each wheat season and following the final wheat harvest, except for the initial sampling where only the primary plots were sampled (APP Table 3). Samples were analyzed for soil nutrient concentration using standard soil test procedures. Soil inorganic nitrogen concentration was extracted using a KCl solution at a 5g soil to 25 ml 1M KCl ratio, shaken for 30 minutes, filtered, and analyzed using a Lachact flow injection analyzer (Hach, Loveland, CO) for nitrate and ammonium concentrations. Total soil nitrogen, which includes both organic and inorganic forms of nitrogen, was analyzed from a 200 mg sub-sample of soil from each sub-plot by an elemental dry combustion analyzer. The analysis by LECO elemental dry combustion (LECO Corp., St. Joseph, MI) also measures total carbon concentration which is multiplied by 1.724 to estimate the soil organic matter content.

Forage Analysis

Harvesting was accomplished using a flail type forage harvester (Carter Mfg. Co., Brookston, IN) by collecting the weight of all biomass at a cutting height of 5 cm from a 1 m x 6 m area in each of the sub plots (Table13) and are expressed as dry biomass yield in mass per area. A sub sample from each of plots was collected for moisture, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), relative feed value (RFV), total digestible nutrients (TDN) and net energy analysis by Oklahoma State Soil Water and Forage Analytical Laboratory (SWAFL). These parameters were both measured and calculated; the measured values are NDF, total nitrogen, and moisture. The calculated values are CP, RFV, TDN, and net energy (Rocateli & Zhang, 2015).

The measured values are determined through in-vitro analysis through direct chemical analysis and near infrared reflectance spectroscopy. Neutral detergent fiber is a measure of the slowly digestible and indigestible fractions of the plant, such as cellulose, hemicellulose, and lignin.

Since this number represents the amount of slowly or non-digestible portion, a smaller value is desirable. NDF is measured by weighing out 0.45 grams of ground dried sample, mixing in NDF solution, and digesting at 100°C for 55 minutes, rinse in water 5 times followed by a 5 minute soak in acetone, then dried at 105°C for 12 hours, the a final weight is taken (Zhang & Henderson, 2016). This value is then divided by the beginning weight to give the percent of material that is consumed. Acid detergent fiber is a sub-fraction of NDF that consists of cellulose and lignin, which are slowly digestible, and represents the forage digestibility (Rocateli & Zhang, 2015). ADF is measured using the same procedure as NDF with the use of an acid solution, to return the amount of digestible forage, as a percentage of total weight.

Total nitrogen is measured from a 0.15 – 0.2 g sample via a dry combustion carbon nitrogen analyzer (LECO; St. Joseph, MI). Moisture was measured by weighing the sub-sample, drying in an oven at 85 °C until a constant moisture content, and weighed again. The final dry weigh divided by the initial wet weight, which is the dry matter percentage. Moisture percent is then calculated as 100 minus the dry matter percent.

The calculated parameters utilize the values measured by one or more of the previously discussed parameters and constants to calculate the quality value of forages. Crude protein is the most common value used when discussing feed quality as it provides amino acids and nitrogen for rumen microbes and the animal itself. To calculate the CP of feed the total N percent is multiplied by the constant value of 6.25, where the assumed N concentration of protein in plant tissue is 16% (Jones, 1931). Relative feed value is a measure of forage quality relative to the typical quality of alfalfa at full bloom, using NDF to predict DMI and ADF to predict digestive dry matter (DDM) in the calculation below.

$$\boldsymbol{RFV} = [\mathbf{88.9} - (\mathbf{0.779} \times \boldsymbol{ADF})] \times \left(\frac{\mathbf{120}}{\boldsymbol{NDF}}\right) \times \mathbf{0.775} \tag{1}$$

Total digestible nutrients is an older method of quantifying energy in forages, this method often over-estimates the value of forages by not accounting for losses such as heat increment and gaseous losses in ruminants. Although TDN does not account for the losses in digestion, it is still a useful forage analysis; TDN is expressed as a fraction and calculated from ADF in the calculation below.

$$\boldsymbol{TDN = 88.9 - (0.779 \times ADF)} \tag{2}$$

Net energy is the portion of energy in ingested forage that is useful to the animal, after losses through feces, gas urine, and work of digestion. There are three classifications of energy for productive purposes: maintenance, lactation, and gain or growth. Net energy-maintenance (NE_m) is the estimate of energy of a forage when used to maintain body weight of a non-productive animal. An animal in maintenance is not losing or gaining weight, producing milk, nor doing any work in its environment (Rocateli & Zhang, 2015). The calculation for NE_m is below.

$$\boldsymbol{NE_m = -0.508 + (1.37 \times 0.01642 \times TDN) - \left[0.3042 \times (0.01642 \times TDN)^2\right] + 0.0593(0.01642 \times TDN)} \tag{3}$$

Another energy calculation is the net energy-lactation (NE_l) that is used when forages are being used for lactating cow in dairy production, the calculation for NE_l is below.

$$\boldsymbol{NE_l = (TDN \times 0.01114) - 0.054} \tag{4}$$

The final estimate of energy of forages when used for body weight gain once maintenance is achieved is called net energy-gain (NE_g) and is calculated using the following equation.

$$NE_g = -0.7484 + 1.42 \times 0.01642 \times TDN - 0.3836 \times (0.01642 \times TDN)^2 + 0.0593 \times (0.01642 \times TDN)^3 \quad (5)$$

Statistical Analysis

Data analysis was conducted using PROC ANOVA procedures (alpha=0.05) in SAS software, version 9.4 (SAS Institute Inc., Cary, NC, USA). Mean separation was conducted using a Fisher's least significant difference analysis.

Results

Chickasha

Climatic conditions in Chickasha influenced the production of the system greatly. Chickasha 2018-2019 had significant rainfall occurring in the fall and winter of 2018 with a total of 412 mm of rainfall from planting until December 31 (Table 14). These precipitation events delayed fall harvest of winter wheat forage until after spring green-up. Summer 2019 was also impacted negatively by the climate, with dry period that is common in the month of July and less than average rainfall in August (Table 14; Figure 3). Two weeks prior to planting of the summer forage crops, 12.2 mm and 19.6mm of precipitation occurred 13d and 9d, respectively, before planting date and with no rainfall event greater than 1mm for 37d after planting date. The total rainfall for the period of summer crop production was 15.5 mm with 93% of this rainfall occurring 37d or more after the planting date.

The fall season of 2019-2020 had less rainfall than the previous year, with only 140 mm of rainfall from planting until January (Table 14). These late fall/early winter rainfall totals were higher than the 20-year average in September but lower in the November and December months (Table 14; Figure 3). A greater than normal amount of precipitation (+1.5mm) in the month of

January. Rainfall patterns were higher than normal for March by 2.1mm and lower than normal for February and April by 0.4mm and 1.3mm, respectively. In the summer of 2020, there was a heavy rainfall event occurring 2d after planting of summer crops and continuing for 7d where 44 mm of rainfall, with 24 mm falling on the first day of the event. A dry period of 20 days with an average temperature of 25 °C and receiving only one event of 5mm of rainfall, followed the heavy rainfall period. The heavy rainfall immediately after planting followed by a hot dry period proved to be detrimental to the establishment of pearl millet.

Rainfall in the 2020-2021 wheat season was much lower and more sporadic than in the previous years (Table 14; Figure 4). This resulted in lower biomass production in both the fall and spring allowing for only one harvest in the 2020-2021 growing season. Groupings of rainfall events greater than 10mm within 2 to 3 day, followed by dry period of no more than 14d occurred more regularly starting in November throughout the season. These sporadic high rainfall events caused ponding in some replications in the 2020-2021 growing season, which led to reduced yields in one replication of the study. Average daily temperatures were also lower for most months of the 2020-2021 growing season (Table 14). The 2020-2021 season also had a late freeze event of average daily temperature below 0°C for three days occurring in late February and early March, only separated by a single day with a temperature of 0.6°C. This late frost resulted in a reduced growth of wheat in early spring which also contributed to the single harvest event.

In the first year of the study wheat growth was adequate for two wheat harvests, see Table 13 for harvest dates. In the first harvest, performed at Feekes 9 - 10, the only N applied was the pre-plant applications of either 67 kg N ha^{-1} or 135 kg N ha^{-1}, as the top-dress 67.35 kg ha^{-1} was not applied at the time of first harvest. Dry matter biomass production was not impacted by N treatment and averaged 4.5 Mg ha^{-1} for the trial. The impact of N rate on wheat forage CP content was significant (Table 15). Crude protein of the forage was increased from an average of 14.7% to 16.2% with the increase of N application rate from 67.25 kg N ha^{-1} to 135 kg N ha^{-1}.

The second and final wheat forage harvest of the season, performed at Feekes 10.5 showed a significant impact of nitrogen rate and timing which can be found in Table 16. This harvest included the application of a 67 kg N ha^{-1} top-dress applied following the first harvest for those treatment with the split application management. Wheat dry matter biomass and CP were both significantly impacted by wheat nitrogen application rate. Dry matter biomass was not significantly impacted by the pre-plant N rate with an average of 8.1 Mg ha^{-1}. The top-dress application of 67 kg N ha^{-1} increased dry matter biomass an average of 1.72 Mg ha^{-1} and 2.58 Mg ha^{-1} compared to the 135 kg N ha^{-1} and 67.28 kg N ha^{-1} pre-plant applications, respectively. Crude protein content was increased by 0.74% due to the increase of pre-plant N rate from 8.6% with the application of 67 kg N ha^{-1} to 9.4%. While the split application of N also resulted in an increase of 1.9% and 1.2% compared to the 67 kg N ha^{-1} and 135 kg ha^{-1} pre-plant rates, respectively. Acid detergent fiber was increased from 35.5% and 35.6% in the 67 kg N ha^{-1} and 135 kg N ha^{-1}, to 36.3% by the split application of N. Total digestible nutrients was decreased from 61.2% in the 67 kg N ha^{-1} and 135 kg N ha^{-1} pre-plant applications to 60.6% due to the split application of N. Net energy for maintenance (NE_m) and lactation (NE_l) were decreased by as much as 0.009% and 0.007%, to 0.605% and 0.622% respectively, with the addition of the 67 kg N ha^{-1} as a top-dress, when compared to pre-plant application regardless of rate. The additional N application decreased the amount of net energy produced by the wheat forage, by utilizing the additional N for biomass production. Increased in N uptake per acre occurred, as expected, by 21.66 kg N ha with the increased nitrogen rate and by 45.65 kg N ha^{-1} from the additional N at top-dress.

Total wheat biomass production from the first year was increased with the split application of 67 kg N ha^{-1} at pre-plant and again at top-dress by an average of 1.85 Mg ha^{-1} greater than the pre-plant applications. The increase of pre-plant application rate resulted in no significant difference in total wheat biomass production in the first year of the study. Nitrogen uptake was also increased in a similar fashion with the split application resulting in an average of at least 40.4 kg ha^{-1} more N taken up by the plant than the pre-plant applications with 216 kg N ha^{-1} taken up by the 67 kg N ha^{-1}, and 238 kg N ha^{-1} taken up by the 135 kg N ha^{-1}. Fertilizer use efficiency (FUE) was different for all wheat nitrogen treatments, with the 67 kg N ha^{-1} having the highest FUE of 322%, followed by the split application having a 207% FUE, and lowest FUE of 177% for the 135 kg N ha^{-1} pre-plant application.

In the summer of 2019, there no measurable forage production due to the lack of precipitation (Table 14) following the planting of the summer crops. Therefore, year one totals for biomass production and total N uptake are the same as those reported for the total wheat production. Summer N application treatments were applied and will be considered in the system totals.

The first harvest of the second year at Chickasha revealed similar results as the first harvest of the first year (table 17). Biomass production was not influenced by any N treatment and yielded an average of 3.1 Mg ha^{-1}. Crude protein content was significantly impacted by wheat and summer N independently. The high rate of 135 kg N ha^{-1} increased the CP by an average of 1.62% over the pre-plant 67 kg N ha^{-1}, however the addition of 34 kg N ha^{-1} in the previous summer decreased the protein concentration by 0.84%. Decreased protein in this harvest could be attributed to an increased N consumption by microbes breaking down plant residues due to the addition of N in the summer. Nitrogen uptake was increased with the 135 kg ha^{-1} pre-plant and split application by 46.2 Mg ha^{-1} and 38.4 Mg ha^{-1}, respectively, in comparison to the 67 kg N ha^{-1} pre-plant application, although the second half of the split application N was not applied by the point of harvest. Which could be attributed to an increased residual amount of N in the higher N rate treatments.

Year two second wheat harvest resulted in an average biomass yield of 6.2 Mg ha^{-1} with no significant results at a 95% confidence level (alpha = 0.05) (Table 18). However, trends did occur with the application of summer N for CP, ADF, TDN, NE_l, and NE_g. Crude protein concentration and ADF both saw a trend of increasing with the preceding summer application of 34 kg N ha^{-1}, while TDN and Net energy values had a tendency to decrease. Year two wheat harvest totals showed significant increases of FUE with the application of wheat N. Similarly, to previous year the 67 kg N ha^{-1} had a higher FUE of 238% compared to the 134% and 125% FUE values of 135 kg N ha^{-1} pre-plant and split applications, respectively, which were not different from one another.

Year two summer had harvestable biomass; however, it was only in cowpea treatments due to lack of millet establishment (N=40). Therefore, cowpea – millet mixture treatments were evaluated as a 0.5 planted rate of 34 kg ha^{-1} cowpeas and the millet treatments are evaluated as fallow treatments. All though the planting rates of cowpea did vary there was no significant response or trend of any dependent variable to cropping method or nitrogen application and treatment averages can be found in Table 19. Significance from previous harvests is reflected in the year two totals and system production totals.

Year two total production resulted in no significance of any treatment on dry matter biomass, with an average of 10 Mg ha^{-1}. The N uptake total for year two was increased by the harvest of a cowpea forage crop by 45.8 kg N ha^{-1} compared to a fallow period. Year two FUE was increased by the interaction of wheat and summer N, as well as, by summer cropping method. The interaction of and summer N applications resulted the greatest FUE from the 67 kg N ha^{-1} and zero summer N combination at 277%. The lowest FUE values (<145%) were acquired with the combinations of split application of 67 kg N ha^{-1} regardless of summer N, and/or the 135 kg N ha^{-1} pre-plant application with a summer N application. Summer crop influenced the FUE as was the N uptake, as N uptake is a factor of FUE, where the cowpea treatments increased the FUE to 191% compared to the FUE of 142% when a fallow period was utilized, regardless of planting rate.

In the third year of the study only one wheat harvest was performed due to environmental impacts such as early cool season, limited precipitation, and late freezing conditions that reduced wheat growth. Ponding of rainfall on the soil surface occurred in one replication, which reduced yield, however replication showed to be non-significant. The result of this single harvest resulted in significant impact of winter wheat N application on dry matter biomass yield and N uptake (Table 20). Dry matter biomass was increased with the use of 135 kg N ha^{-1} at pre-plant by 0.92 Mg ha^{-1} and 1.6 Mg ha^{-1} when compared to the split application and 67 kg N ha^{-1} pre-plant application, respectively. N uptake followed the same pattern as in previous harvests where the increased rate of 135 kg N ha^{-1} led to increased (≥53.87 kg N ha^{-1}) uptake regardless of the application method.

Over three years of the study winter wheat dry matter production results were significantly impacted by wheat N and summer management (Table 21). Nitrogen rates of 135 kg N ha^{-1} increased yield by up to 3.7 Mg ha^{-1}, regardless of application method, compared to the pre-plant application of 67 kg N ha^{-1}. The three-year total wheat yields were highest when fallow was used as opposed to the cowpea summer forage crop by 2.41 Mg ha^{-1} and 3.77 Mg ha^{-1}, respectively. The use of a 34 kg ha^{-1} cowpea planting (50% rate) or fallow period increased dry matter biomass yields by 2.6 Mg ha^{-1}compared to the use of a full planting rate but was not significantly difference from one another.

Total N uptake for all three wheat years was significantly increased by wheat N application rate, similar to yield as it is a factor of yield by N concentration, N uptake data can be found in Table 21. The utilization of a 135 kg N ha^{-1} rate, regardless of application timing, showed to increase the yields of wheat compared to the pre-plant application of 67 kg N ha^{-1}.

The total system production, an accumulation of all crops overall years, produced significant differences induced by wheat N treatment, summer N treatment and summer management. Total dry matter biomass yield of all 5 cropping seasons were improved an average of 2.8 Mg ha^{-1} to

4.0 Mg ha^{-1} with the use of 135 kg N ha^{-1} regardless of application method (Table 23). With the increase in biomass yield due to N rate the total N uptake and FUE for all cropping systems was also similarly impacted summer N application of 34 kg N ha^{-1} however decreased the FUE of the overall system from 183% to 160% (Table 24; Table 25).

Lake Carl Blackwell

The climate conditions for the Lake Carl Blackwell location were more ideal for a continuous forage production system than what occurred at the Chickasha location. Rainfall during the wheat seasons were much more uniform with a total of 568mm, 538mm, and 470 mm in the wheat growing months of the 2018-2019, 2019-2020, and 2020-2021 growing seasons, respectively (Table 14). Temperatures for the 2018-2019 growing season were cooler in the late fall and early spring months than the 20-year average, with warmer summer months (Table 14; Figure 4). While the 2019-2020 wheat growing season had warmer fall months than the 20 year average with cooler winter temperatures, with similar summer conditions (Table 14; Figure 4). Cooler early fall and warmer late fall average temperatures occurred in 2020-2021, while the month of February had much cooler temperatures than observed on average for this location (Table 14; Figure 4). Like the Chickasha location there were freezing events that occurred late in the growing season in 2021. At LCB there was a 14d period in mid-February (7, February – 20, February) where temperatures were below -2°C, with an average temperature of -10°C. These conditions of colder than average early fall and early spring freeze resulted in less winter wheat growth in the 2020-2021 wheat production season.

The first year of the study at the produced enough forage for a late fall cutting near Feekes 4 as well as a final cutting near boot stage (Feekes 10). The first harvest at the site resulted in significance impact of nitrogen to all measured forage parameters, results can be found in Table 26. In the first harvest, similar to the first harvest at the Chickasha location the split application was not applied until following spring green up, therefore pre-plant rate is the only analyzed treatment. The use of 135 kg N ha^{-1} increased the dry matter biomass and CP content by 0.77 Mg ha and 2.2%, respectively, compared to the use of a 67 kg N ha^{-1} rate. Acid detergent fiber, which is the quantity of forage that is slowly digestible, was decreased from 26.6% to 25.0% when the pre-plant N application rate was increased to 135 kg N ha^{--1}. While TDN was increased, by 1.18% with the increased N rate, to 69.4%. Net energy for lactation, maintenance, and gain were all increased using 135 kg N ha^{-1}, compared to a 67 kg N ha^{-1} rate, by 0.015%, 0.014%, and 0.016%, respectively. Total N uptake was also increased from an average of 25.5 kg N ha^{-} to 47 kg N ha^{-1} when the N rate was increased to 135 kg N ha^{-1}.

In the second harvest of the first year, less significant effects were observed but many trends were still present in the data (Table 27). Dry matter biomass yield was increased by pre-plant N application rate, where the increased pre-plant rate of 135 kg N ha^{-1} produced 9.7 Mg ha^{-1} which was 1.9 Mg ha^{-1} more biomass than the 67 kg N ha^{-1} pre-plant rate. Dry matter biomass was increased by an additional 3.7 Mg ha^{-1} when the 135 kg N ha^{-1} was split applied compared to pre-plant. Crude protein concentrations were lower in the final harvest of wheat than the first harvest, but they were increased by an average of 1.2% with the additional 67 kg N ha^{-1} from the split application (6.6%). Nitrogen uptake from the final harvest was similar to the results of biomass yield as it is a factor of yield and crude protein. Increased N uptake from 67.8 kg N ha^{-1} to 84.4 kg N ha^{-1} was seen when the pre-plant N rate was increased, while the split application of N increased N uptake to 141.6 kg N ha^{-1}.

Year one total wheat production was impacted by nitrogen application for total dry matter biomass, total N uptake, and FUE. Total dry matter production and total N uptake were increased by the increase in N application rate from 9.1 Mg ha^{-1} to 11.9 Mg ha^{-1} and 82.0 kg N ha^{-1} to 117.3 kg N ha^{-1}, respectively. When N was split applied, dry matter yield was increased to 17.8 Mg ha^{-1} and N uptake was increased to 150 kg N ha^{-1}.

Summer crops in year one had an infestation of crabgrass that overcame the pearl millet. Crabgrass coverage was visually rated as a percent of crabgrass coverage. The percent crabgrass was influenced by summer crop system, where millet plots had an average of 78% crabgrass, this is at least 52% higher than cowpeas (19%) and mixed (26%) treatments. The high concentration of crabgrass out competed millet resulting in no millet in the 2019 summer forage harvest. However, crabgrass production was measured in all treatments, and results form 2019 summer can be found in Table 28. Summer forage yields were increased with the addition of 34 kg N ha^{-1} by 0.56 Mg ha^{-1} greater than when no N was used (0.89 Mg ha^{-1}). Cowpea regardless, if planted as monoculture or mixed, increased dry matter biomass yields to 2.7 Mg ha^{-1}, compared to 1.5 Mg ha^{-1} of crabgrass. Crude protein concentration was reduced by 1.9% with the addition of 34 kg N ha^{-1}, compared to no N application with 11.12% C, however, similar to dry matter yield, it was increased with the use of cowpeas, regardless of mixture, from 6.9% to 11.9%. Nitrogen uptake was increased by 37.3 kg N ha^{-1} with the use of a cowpea summer forage crop, compared to crabgrass (15.9 kg N ha^{-1}).

Year one total production results in more significant effects of wheat nitrogen application, summer nitrogen application, and summer system. Total dry matter yield production from the first years was increased by 2.7 Mg ha^{-1} to 13.6 Mg ha^{-1} when the pre-plant N rate was increased to 135 kg N ha^{-1}, however N was split applied the yield was increased to 16.5 Mg ha^{-1}. The use of a summer forage crop also increased the total dry matter yield of the first year to an average of 14.3 Mg ha^{-1}, regardless of summer crop species, compared to 11.7 Mg ha^{-1} when a fallow period was used. Total N uptake for year one production was increased similarly to yield with N uptake increase of 35.5 kg N ha^{-1} for the 135 kg N ha^{-1} pre-plant rate (160 kg N ha^{-1}) and 72.8 kg N ha^{-1} for the split application (197 kg N ha^{-1}), compared to the 67 kg ha^{-1} pre-plant rate. The use of only a cowpea summer crop resulted in the greatest N uptake of 194 kg N ha^{-1} for year one production, followed by crabgrass-cowpea mixture and crabgrass of 174 kg N ha^{-1} and 150 kg N ha^{-1}, respectively. The fallow period had less N uptake than all forage crops in the first year with 125 kg N ha^{-1} taken up.

The second wheat crop had sufficient growth to result in two harvests, although the first harvest happened after spring green-up (Feekes 5) due to limited fall growth. Winter wheat N application, as well as summer forage crop, impacted all parameters of wheat forage production in the first harvest (Table 29). Summer N application impacted the forage quality, while there an interaction of wheat N application and summer management on the total N uptake of year two first harvest.

Winter wheat dry matter yield was increased by the 135 kg N ha^{-1} pre-plan rate to 2.9 Mg ha^{-1}, which was 1.2 Mg ha^{-1} and 1.3 Mg ha^{-1} greater than the 67 kg N ha^{-1} pre-plant and the split application treatments, respectively. The use of a summer fallow period increased the winter wheat yields 0.34 Mg ha^{-1} on average to 1.2 Mg ha^{-1}, compared to the use of any summer crop evaluated. This led to the trend of an interaction between the wheat N application and the summer crop. Crude protein concentration of the first harvest had similar results for wheat N application as dry matter yield, where CP was increased to 15% with the application of 135 kg N ha^{-1}, which was on average 1.6% greater than the 67 kg N ha^{-1} of pre-plant and split applications. Like the results of the same harvest at Chickasha summer N application of 34 kg N ha^{-1} decreased wheat CP of the first harvest by 0.6% to 13.7%. Crabgrass and cowpea-crabgrass mixtures decreased wheat CP by 1.1% compared to a fallow period (14.7%). Cowpea forage crop had 14.2% CP which was 0.6% higher than crabgrass (13.6%), but not different from the mixture or fallow treatments.

Winter wheat ADF was decreased by 1.7% and 2.7% with the 135 kg N ha^{-1} pre-plant rate, compared to the 67 kg N ha^{-1} pre-plant (24.2%) and split applications (23.2%), however, it was increased by the summer application of 34 kg N ha^{-1} from 13.7% to 14.3%. Crabgrass increased wheat ADF to 24.2% compared to 21.8% and 22.3% of the fallow and cowpeas, respectively.

When cowpeas were mixed with the crabgrass the ADF concentration was increased by 1.9% compared to fallow and 1.4% compared to monoculture cowpeas. This also led to a trend of an interaction between the wheat N application by summer forage crop selection. Total digestible nutrients were increased with the 135 kg N ha^{-1} rate by 1.69% on average compared to pre-plant 67 kg N ha^{-1} and split N applications (70.4%). The use of a summer N application decreased the TDN of the first harvest of wheat in the second year by 1% to 70.5%. Crabgrass, including when present in a mixture, reduced the TDN of the subsequent wheat crop by an average of 1.3% and 1.7% when compared to 71.5% from the cowpea, and 71.9% from the summer fallow treatments.

Net energy parameters were all impacted similarly by wheat N and summer N application, with only minor differences in their response to summer crops. Net energy for maintenance was increased to 0.77% by the 135 kg N ha^{-1} at pre-plant application which was an average of 0.02% higher than the 67 kg N ha^{-1} from the pre-plant or split applications. The application of 34 kg N ha^{-1} during the previous summer decreased the NE_m by 0.01% to 0.75%. Crabgrass, used, decreased the NE_m by 0.02% compared to cowpeas (0.76%), and by 0.02% compared to a summer fallow (0.77%), regardless if used or in a mixture with cowpeas.

Net energy for lactation was increased to 0.75% when 135 kg N ha^{-1} was applied as a pre-plant compared to 67 kg N ha^{-1} pre-plant and split application with an average of 0.73% NE_l. Application of 34 kg N ha^{-1} summer N decreased the NE_l by 0.01%, similar to the NE_m. Summer forage impact on subsequent wheat was significant where the crabgrass decreased NE_l by an average of 0.02 compared to fallow (0.75%) and cowpea (0.74%), regardless if mixture with cowpeas. Similarly, crabgrass monoculture or mixed with cowpeas, decreased NE_m by 0.01% compared to a summer fallow.

Net energy for gain was impacted similarly to the other energy parameters, where the increased pre-plant rate of 135 kg N ha^{-1} increased the wheat NE_g by 0.02% compared to both the pre-plant and split application 67 kg N ha^{-1}. It was also similarly decreased by summer N application, where the addition of summer N decreased the NE_g by 0.01%. Summer forage crop of crabgrass regardless of mixture decreased the NE_g by 0.02% on average compared to cowpea (0.49%) or fallow (0.49%). Non-significant trends were observed for the net energy parameters with the interaction of summer crop and wheat N application.

A significant interaction for total N uptake was observed by summer system and wheat N rate for the second year first wheat harvest (Table 29). The combination of a 135 kg N ha^{-1} pre-plant following a fallow summer period had the highest N uptake in the wheat of 104 kg ha^{-1}. The next highest N uptake of 70 kg N ha^{-1} came from the combination of 135 kg N ha^{-1} following crabgrass, which was not significantly different from the same N rate following the crabgrass cowpea mixture. The use of a split application following a summer crop, regardless of species, resulted in the lowest numerical N uptake of less than 33 kg N ha^{-1}.

Winter wheat final harvest of year two resulted in significance for dry matter yield, CP, and N uptake (Table 30). Dry matter yield was increased to 5.2 Mg ha^{-1} by the 135 kg N ha^{-1} N pre-plant application rate from 3.7 kg N ha^{-1} for the 67 kg N ha^{-1} pre-plant rate, when the increase N rate was split applied biomass yield was increased to 6.4 Mg ha^{-1}. The addition of N in the preceding summer reduced wheat dry matter yield from 5.3 Mg ha^{-1} to 4.9 Mg ha^{-1}. When wheat followed a fallow period the dry matter biomass production was increased by at least 0.4 Mg ha^{-1} to 5.6 Mg ha^{-1}, while following a cowpea forage crop (5.2 Mg ha^{-1}) improved wheat biomass production by 0.5 Mg ha^{-1} compared to crabgrass forage, regardless of mixed or monoculture. This led to a trend of a three-way interaction of wheat N application , summer system, and summer N application, although it was not significant at alpha = 0.05.

Winter wheat CP concentration from the final harvest of the second year was increased similarly to biomass yield. The increased rate of 135 kg N ha^{-1} increased CP from 9.2% to 9.8%, increased greater to 10.8% when N was split applied. Total N uptake of year two final harvest wheat produced a significant interaction of wheat nitrogen, summer nitrogen, and summer crop. This interaction resulted in the highest numerical N uptake being produced with the use of split application of wheat N when following a fallow period with the addition of 34 kg N ha^{-1}. Although this treatment was not significantly different from any other split application interactions, with the exception of when the fallow period was replaced with a crabgrass, regardless of summer N application. When wheat followed a summer crop and received 67 kg N ha^{-1} the lowest N uptake occurred with 51 kg N ha^{-1} or less.

Total wheat forage dry matter production in the second year was influenced by the application of N to the wheat and summer system. Winter wheat N applications of 135 kg N ha^{-1} increased the total dry matter yield produced from 5.5 Mg ha^{-1} by 2.6 Mg ha^{-1} in the second year, regardless of the application timing. When wheat followed a fallow period total yield was 8.2 Mg ha^{-1} compared to when wheat followed any summer forage with an average yield of 6.9 Mg ha^{-1}.

Total N uptake of year two wheat was increased by a three way interaction of a wheat N application, summer system, and summer N application. Total N uptake for wheat was increased the most by the combination of 135 kg N ha^{-1} at pre-plant and a non-fertilized fallow period or a split wheat N application totaling 135 kg N ha^{-1} following a fallow period fertilized with 34 kg N ha^{-1} with an average of 206 kg N ha^{-1}. The use of 67 kg N ha^{-1} at pre-plant alone typically had the lowest N uptake, regardless of summer N application o cropping system with an average of 93 kg N ha^{-1}. The lowest N uptake of 82 kg N ha^{-1} came with the use of 67.15 kg N ha^{-1} pre-plant, following a fertilized crabgrass treatment.

Year two summer had visually uniform crabgrass coverage in all millet plots and millet-cowpeas plots, similar to the first summer at the Lake Carl Blackwell location. Dry matter forage in the summer was influenced by the application of summer N, as well as by an interaction of wheat N application and summer system (Table 31). The application of N to the summer crop increased dry matter yield by 1.5 Mg ha^{-1} compared to when no N was applied (1.2 $Mgha^{-1}$). The interaction of summer crop and wheat N indicated that when the crabgrass-cowpea mixture followed the 135 kg N ha^{-1} per-plant rate the yield was 5.3 Mg ha^{-1}, which was higher than all other summer forages except cowpea following the split wheat N application (5.0 Mg ha^{-1}) and the crabgrass-cowpea mixture following a single 67 kg N ha^{-1} pre-plant application (4.6 Mg ha^{-1}). The lowest numerical yield was produced by the crabgrass treatments, regardless of wheat N, with an average yield of 2.5 Mg ha^{-1}.

Summer forage CP was impacted by N application and species (Table 31). The CP was generally lower when 34 kg N ha^{-1} was applied to the crop at 10% in comparison to no N by 1.5%. While the CP was increased to 11.7% using a cowpea crop, regardless of singularly or in a mixture, compared to crabgrass with a CP of 8.8%. The quality parameters of the summer forages were influenced by the interaction of summer N application and species. Acid detergent fiber content was decreased when the cowpeas were used without an N application with an average ADF of 35.7%, which was lower than all other treatment combinations (40% ADF). Total digestible nutrients, NE_m, NE_l, and NE_g were increased by the use of no N application on cowpeas regardless of mixture, with an average of 3.4%, 0.61%, 0.63%, and 0.35%, respectively, compared to all other combination of summer N and species, which averaged 0.56% NE_m, 0.59% NE_l, and 0.30% NE_g.

Nitrogen uptake by the summer crops were influenced by the application of summer N, and the interaction between wheat N application and summer species. The application of

34 kg N ha^{-1} to the summer crops resulted in a 23 kg N ha^{-1} increase in the N uptake of the summer crops (75 kg N ha^{-1}). The interaction of wheat nitrogen application and summer crop increased the N uptake similar to the increases in yield. The use of a cowpea – crabgrass mixture following a 67 kg N ha^{-1} or 135 kg N ha^{-1} pre-plant wheat N rate and cowpeas following a split wheat N application had the highest total N uptake with an average of 92 kg N ha^{-1}. A single 67 kg N ha^{-1} wheat application followed by a crabgrass yielded the lowest numerical N uptake of 29 kg N ha^{-1}.

Year two wheat total dry matter yield resulted in an interaction of wheat N application and summer cropping system, as well as an interaction between summer cropping system and summer N application. The wheat N and summer cropping method interaction indicated that the use of 135 kg N ha^{-1} pre-plant wheat application followed by a crabgrass – cowpea mixture and the split application of wheat N followed by a cowpea crop produced the greatest yields of 13.2 Mg ha^{-1}, on average. The 67 kg N ha^{-1} wheat application followed by a fallow period produced the lowest numerical dry matter yield of 6.4 Mg ha^{-1}. The 67 kg N ha^{-1} wheat N following crabgrass was not different from the fallow period or cowpea with the same wheat N application. The interaction of summer N and summer system also influenced the second season of wheat production, where the use of a fallow period with or without a summer N application or the use of crabgrass crop with no N application produced the lowest yields of 8 Mg ha^{-1}, compared to all other treatments which averaged 11 Mg ha^{-1}.

Total N uptake for year two was impacted as a three-way interaction of wheat N application, summer N, and summer system. The combination of a pre-plant 67 kg N ha^{-1} wheat N application and crabgrass without summer N application had the lowest N uptake of 91 kg N ha^{-1}, which was different from all treatments except 67 kg N ha^{-1} wheat pre-plant N following a fallow period with or without summer N, and the split application of wheat N following a fertilized summer crabgrass. While the combinations of a split application of wheat N followed by cowpeas with no summer N, 135 kg N ha^{-1} followed by a cowpea - crabgrass mixture with and without N produced the highest numerical N uptake, compared to all other treatments in the study, with an average N uptake yield of 248 kg N ha^{-1}.

Year two FUE for the Lake Carl Blackwell location was increased by the interaction of wheat N application, summer cropping method, and summer N. The combination of a 67 kg N ha^{-1} pre-plant rate followed by the mix of crabgrass and cowpeas with no additional summer N had an FUE of 262%, 46% greater than all other treatment combinations. The lowest numerical FUE of 92% was achieved with the combination of 135 kg N ha^{-1} pre-plant wheat N followed by a fallow period that had an additional 30 kg N ha^{-1} applied to it.

Similar to the final year at the Chickasha; the Lake Carl Blackwell location had less fall and early spring growth resulting in a single harvest for the third and final year of the trail. In the third year the dry matter production was influenced by wheat N application and summer N application, results can be found in Table 32. This season the utilization of 135 kg N ha^{-1} increased the dry matter production of 5.3 Mg ha^{1}, regardless of application method, which was 1.8 Mg ha^{-1} greater than the 67 kg N ha, pre-plant rate. The application of 34 kg N ha^{-1} in the previous summer also increased dry matter production from 4.5 Mg ha^{-1} to 4.9 Mg ha^{-1}.

Crude protein concentration of the final harvest was increased by the split application of wheat N to 11.3%, which was 2.4% on average, higher than either pre-plant application. Acid detergent fiber was increased with the combination of no summer N application to the cowpeas – crabgrass mixture, to 34% which was greater than any other treatment by at least 2.7%.

Total digestible nutrients was influenced by the interaction between summer crop and summer N applications. The combination of no summer N and a crabgrass-cowpea mixture resulted in 62% TDN in the subsequent wheat forage, which was at least 2.1% lower than all other treatment combinations.

Net energy of all three parameters, maintenance, lactation, and gain, in the final harvest of the study were impacted similar to TDN by the interaction of summer N application and summer cropping method,. The interaction of a crabgrass-cowpea mixture with no N applied resulted in 0.63% NE_m, 0.64% NE_l, and 0.37% NE_g, lower than all other treatment combinations by at least 0.2%, 0.3%, and 0.2%, respectively.

Total N uptake of the final harvest at the Lake Carl Blackwell location was significantly impacted by the wheat N application and the previous summer N application. The increase of pre-plant application rate for 67 kg N ha^{-1} to 135 kg N ha^{-1} increased the total N uptake from 51 kg N ha^{-1} to 74 kg N ha^{-1}, while the split application increased the total N uptake to 97 kg ha^{-1}. The application of a summer N in the preceding summer resulted in the increased uptake of N in the final wheat forage harvest to 79 kg N ha^{-1} compared to 70 kg N ha^{-1} when no N was applied.

Three-year cumulative wheat production shows to be influenced by wheat N applications as well as summer crop (Table 33). The total wheat dry matter production from the three years was increased by 7.4 Mg ha^{-1} when the N rate was increased from 67 kg N ha^{-1} to 135 kg N ha^{-1} in the pre-plant application, to 25 Mg ha^{-1}. When the N was applied as a split application, an additional 3 Mg ha^{-1} of dry matter was produced, compared to the 135 kg ha^{-1} pre-plant rate. When wheat followed a fallow period all three years the dry matter was increased to an average of 25 Mg ha^{-1}, which was 1.8 Mg ha^{-1} higher, on average, than a crabgrass forage.

Total N uptake of all three wheat production years (Table 34) was also increased from 235 kg N ha^{-1} with 67 kg N ha^{-1} to 359 kg ha^{-1} with 135 kg N ha^{-1} and when N was split applied further increases N uptake to 412 kg N ha^{-1} was observed. Total N uptake in wheat was also increased when wheat followed a fallow period by to 357 kg N ha^{-1} compared to when following crabgrass or crabgrass-cowpea mixture with an average of 322 kg N ha^{-1}. The use of 67 kg N ha^{-1} in wheat resulted in the lowest N uptake values, regardless of the use of summer N, of 235 kg N ha^{-1} on average.

Total yield production of the system over all three years (Table 35) resulted in significance for wheat N, summer N, and summer cropping method. wheat N increased production of dry matter from 22 Mg ha^{-1} due to 67 kg N ha^{-1} to 30 Mg ha^{-1} with 135 kg N ha^{-1}. A 2.9 Mg ha^{-1} increase over the increased N rate occurred when N was split applied. The addition of 34 kg N ha^{-1} in the summer, increased the production of a system by 1.8 Mg ha^{-1} to 29 Mg ha^{-1}. When cowpeas were used, the dry matter production of the system averaged 30 Mg ha^{-1}, which was 1.4 Mg ha^{-1} and 2.5 Mg ha^{-1} greater than crabgrass and a fallow period, respectively.

The total N uptake of the three years of the overall study resulted in increases due to wheat N and summer cropping method (Table 36). The split application of wheat N resulted in the highest N uptake, of 487 kg N ha^{-1}, which was 47 kg N ha^{-1} and 175 kg N ha^{-1} greater than 135 kg N ha^{-1} and 67 kg N ha^{-1} pre-plant rates, respectively. When wheat was used with a cowpea forage crop, as monoculture or mixed with crabgrass, the total N uptake for the system was 461 kg N ha^{-1} on average, which was greater than the crabgrass crop or a fallow summer period which averaged 365 kg N ha^{-1}.

Overall FUE was influenced by wheat N application and summer system and results can be found in Table 37. As the N rate was increased at pre-plant from 67 kg N ha^{-1} to 135 kg N ha^{-1} the FUE was decreased from 143% to 105%, while when the N was split applied the FUE was 155%. FUE was increased to 136% when a cowpea, regardless if monoculture or mixed, was used as a summer forage crop compared with a crabgrass or fallow period by an average of 30%. The 135 kg N ha^{-1} pre-plant and split applications produced to the lowest FUE values of less than 107% when used with a crabgrass forage crop or a fallow period.

Discussion

The results of this study show major influence of location, which is to be expected with the difference in precipitation and temperatures presented in Table 5. Also, at the Chickasha location the study was implemented into a wheat – legume rotation which resulted in high quantities of residual N for wheat production, whereas the Lake Carl Blackwell location was implemented into a continuous wheat system that was managed for N draw down. This represents two unique systems present in central Oklahoma wheat production.

In the 2018-2019 wheat season both locations received enough rainfall to allow for a multiple harvest situation with Chickasha and Lake Carl Blackwell (LCB) locations receiving 472 mm and 238 mm between planting and the first harvest dates (Table 5). The applied treatments at the time of first harvest were pre-plant applications of 67 kg N ha^{-1} and 135 kg N ha^{-1}, the second half of the split application was applied following spring green-up/first harvest. The first harvest at Chickasha was delayed until after spring green-up due to precipitation preventing similar harvest timing as the LCB. While in the second year both locations first harvest was delayed until after spring green-up due to limited growth with earlier cool season and less precipitation as the wheat matured. Final year, 2020-2021, at both locations only one harvest was made due to cooler average daily temperatures in the early months of growth followed by an early spring freeze which caused a production setback for wheat in 2021

Due the delay in harvest and high residual N concentration in the first year at the Chickasha location the biomass production was greater, however the influence of N application was much less than observed at the Lake Carl Blackwell location. While the Lake Carl Blackwell had lower biomass production, but the influence of N was much more impactful on the quantity of the forage produced. Second year first harvest also had no significant results, which authors attribute to a balance in the system due to no summer crop. First harvest in years 2018-2019 and 2019-2020 resulted in dry matter biomass production increases at the LCB location with the addition of N at pre-plant similar to the increases in wheat biomass production reported by other studies (Gagnon et al., 2019; Khalil et al., 2011; Thomason et al., 2000). Wheat dry matter biomass also decreased when wheat was following a summer forage crop compared to the traditional summer fallow period, at LCB in 2019-2020. Lyon et al. (2004) and Nielsen et al. (2017) reported similar findings of decreasing wheat grain yields when they followed a summer forage crop.

Final wheat harvest of all site years, except Chickasha 2019-2020 and 2020-2021 at both locations, resulted in the application of additional N increasing dry matter biomass. While the increased pre-plant N produced greater biomass, the increases were even greater when the additional N was delayed until top-dress. This increase in dry matter yield with N application was reflected in the total wheat dry matter biomass production from the first year if this study. The split application of 67 kg N ha^{-1} at pre-plant and followed by 67 kg N ha^{-1} at top-dress is similar to the findings of Naveed et al. (2013) who saw the application of 50% N at sowing and 50% N after cutting to yield greater biomass than other combinations, except a 75%/25% application.

Naveed et al. (2013) also found the application of 100% N at pre-plant yield the second highest significant impact on dry matter biomass. The final harvest of 2019-2020 at LCB also had similar summer crop influence of the summer fallow period increasing wheat yields greater than any summer forage crop, as well as an interesting summer N application impact. Where the additional N in the preceding summer actually decreased the wheat yields in the following season. This is similar to other studies which have found decreased wheat grain yields when wheat follows organic N applications (Hayat et al., 2008; Hidayatullah et al., 2013).

The final wheat harvest in the third year at both locations resulted in an increase in dry matter production occurring due to the increased pre-plant N application of 135 kg N ha^{-1}. This was unlike previous years and is hypothesized to be attributed to a greater amount of N available in the soil following the season due to limited fall growth which allowed for earlier N uptake and biomass production. At the Lake Carl Blackwell location, the final harvest dry matter biomass production was increased by summer N application, unlike the response following the first harvest. High residual N concentration is to be the cause of the increased dry matter yields, similar increases in white lupin (*Lupinus albus*) as reported by (Wiatrak et al., 2004a).

Total wheat production from each year was impacted by treatments similar to the individual harvests in each year. Chickasha total wheat dry matter production was increased by the split application of N in the first year, the 135kg N ha^{-1} in the third year, while the split application was also greater than the low pre-plant rate. LCB wheat dry matter was increased by the split application of wheat in in year one, and rate, regardless of timing, in year two and three. The use of a summer crop decreased wheat dry matter production in the second year only, while summer N increased the third year wheat total dry matter production.

Summer cropping seasons had challenges unique to each site year, in 2019 Chickasha had a 46d dry period with less than 1mm rainfall with an average temperature of 27.8 °C starting 8d before planting and continuing for 38 days after planting. This hot dry period prevented summer forage crop establishment which resulted in no summer forage production for Chickasha in 2019. While in the 2020 summer had a heavy rainfall totaling 43mm in the 5d following planting followed by an additional 5 mm 14d after planting followed by a 14d dry period with 77°C average daily temperature. This intermittent heavy rainfall and warm periods resulted in minimal growth of both millet and cowpeas. Lake Carl Blackwell also had challenges, with an invasive crabgrass that flushed in all plots containing pearl millet and thus out competing the millet both years, due to this the crabgrass was harvest in place of the pearl millet as the grassy summer forage crop at LCB.

Summer 2020 dry matter production at Chickasha resulted in no significance, and was the only summer to produce forage. However, LCB had summer N and summer crop influence in both years with the summer crop interacting with wheat N application in the second year. The use of a 34 kg N ha^{-1} summer application increased dry matter production as expected by 0.7 Mg ha^{-1} and 1.9 Mg ha^{-1}, respectively, in 2019 and 2020. Linear increases in crabgrass and cowpea forage yields as N rate increases have been observed in other studies (Asangla & Gohain, 2016; Hasan et al., 2010; Sultana et al., 2005; Teutsch et al., 2005). Cowpeas, in 2019, increased the yields in the summer by at least 1.15 Mg ha^{-1} compared to the use of a crabgrass forage crop. Nguluve et al. (2004) reported legumes to yield higher when grown in monoculture than when mixed with crabgrass, as well as yield greater amounts of biomass than only crabgrass.

In the summer of 2020 at LCB cowpeas also reported greatest dry matter yield when mixed with the crabgrass following a 135 kg N ha^{-1} wheat application. However, the monoculture cowpeas were not significantly lower, but numerically. This increased yield in the mixed treatment is likely due to increased crabgrass stand in the second year, as it was allowed to grow and seed, the first summer. Similar results were observed by Nguluve et al. (2004) that saw in the second year of studies that contained crabgrass, the legume crops were outcompeted earlier than in the first year, resulting in greater yields from crabgrass mixture plots.

The cumulative wheat dry matter production from all three years of the study was only influenced by the N application to the wheat at both locations and the influence of summer cropping method at the Chickasha location. The influence of wheat N was different for the two locations where the application of 135 kg N ha^{-1} increased the dry matter production at both locations, however the split application of that equivalent rate was no different than a pre-plant application at Chickasha. While at LCB the split application increased the total biomass production compared to the same rate at pre-plant. This can be attributed to the influence of timely harvests, residual soil nitrate levels, and influence of summer crop each year which was not significant at LCB but did have a trend of influence. Chickasha wheat dry matter yields resulted in an influence of summer crop for the one summer of established crop, where the use of a fallow period increased wheat biomass production greatest followed by a millet-cowpea mixture which resulted in greater wheat biomass compared to the use of cowpeas alone. Lake Carl Blackwell had a trend for similar increases in wheat biomass following a fallow period. Many studies report reduction in wheat yields following a summer forage crop (Blanco-Canqui et al., 2013a; Holman et al., 2016; Horn et al., 2021; Lyon et al., 2004; Nielsen et al., 2017) however, several report that there is no negative influence on the total system productivity.

Total productivity of the system was measured cumulatively after the collection of year two summer data and trial conclusion. The dry mater production of the system for these cumulative system measurements shows the production of the system to be influenced by the application of wheat N and the summer cropping system at both locations, as well as a summer N application at LCB. Where for all cumulative measurements, except three-year cumulative dry matter production at Chickasha, the application of 67 kg N ha^{-1} at pre-plant and again at top-dress increased the dry matter production of the system. Three-year dry matter accumulation at Chickasha was influenced by wheat N rate increase from 67 kg Nha^{-1} to 135 kg N ha^{-1} regardless of the application timing.

Summer crop impact on the system production was different by location, where at Chickasha the production was increased by the use of a fallow period or summer forage mixture of cowpeas, regardless of monoculture or mixed. While at LCB the use of cowpeas, regardless of planting alone or in a mixture, increased the total dry matter production greater than fallow period or crabgrass summer forage crop. The application of N during the summer at LCB increased the total dry matter production by 1 Mg ha^{-1} and 1.8 Mg ha^{-1} in 2019 and 202, respectively, while Chickasha resulted in a similar trend for summer N. This is similar to the increase of 1 Mg ha^{-1} dry matter biomass with the addition of 30 kg N ha^{-1} as reported by Arnall et al. (2018).

Biomass harvest is important in the discussion of forage production however, as biomass is removed from the system nitrogen is also removed. To evaluate the amount of N removed from the soil system during biomass harvest the total N uptake was calculated as the total nitrogen content of forage multiplied by the quantity of forage. Increases in Total N uptake were observed due to the increase of wheat pre-plant rates as well as wheat split N application at all calculated intervals except, 2018-2019 first harvest, 2019 and 2020 Summer, and year two cumulative total. The first harvest of 2018-2019 as well as the second-year cumulative total were only influenced by the increased pre-plant rate of 135 kg N ha^{-1} at LCB, neither of which were influenced by wheat N application at Chickasha. Increasing the rate of N applied has been reported, as expected, to increase N uptake by others (Beyaert & Roy, 2005; Rostamza et al., 2011)

Summer harvests at LCB were influenced different from one another such as with the use of cowpea, in 2019, which was also the case for LCB two and three year cumulative as well as 2019-2020 total production at Chickasha. While 2020 summer N uptake was increased by the application of 34 kg N ha^{-1} as well as increasing the N uptake in the following wheat crop in 2020-2021 at LCB. Summer 2020 of LCB had numerically greatest uptake with the combination of a cowpea – crabgrass following a 135 kg N ha^{-1} pre-plant wheat application. Which has been reported to occur with the introduction of a legume into a grass species crop (Nyfeler et al., 2011; Suter et al., 2015).

Other interactions were also seen such as the split application of a wheat N following a cowpeas, which had the greater N uptake in the first harvest of LCB 2019-2020 than any combination of 67 kg N ha^{-1} pre-plant wheat application. While the total wheat production of the 2019-2020 wheat season was increased by 135 kg N ha^{-1} was applied pre-plant following a fallow period summer with no N application. This one-time event of increased uptake could be attributed to the increased availability of N to the following wheat crop due to not having any removal from a summer forage crop. While the total year two N uptake was increased greatest, numerically, by the use of a split application of wheat N followed by cowpeas with no N. Similar results were found by Nyfeler et al. (2011) who found the use of a legume crop increased the N uptake of grasses, while the addition of N to the legumes decreased the N uptake of the grasses with each additional increment of N applied.

As expected, the addition of N to each individual cropping system increased N uptake while typically the use of a cowpea crop alone mixed resulted in the N uptake increases in instances when summer cropping method played a role. Total N uptake accounts for all N removed from the soil by the aboveground harvested biomass, which can be used to access the draw a continuous forage production system can have on a soil system. This draw on the system can be replenished by the addition of N fertilizers, which can become available for plant uptake. The amount of this fertilizer that is taken up by the plant is considered the fertilizer use efficiency (FUE). To calculate the FUE the amount of N uptake is divided by the amount of nitrogen applied, 100% FUE represents total fertilizer usage and anything greater than that is residual soil N removal.

Since FUE is the amount of fertilizer used, it is often that FUE will be greater in lower N treatments as experienced in all instances of significance. This occurred with wheat N application for all individual wheat production seasons at both locations, as well as LCB 2018-2019 total production, and three year cumulative wheat and cumulative system production at both locations. Similar responses have been observed in many NUE studies, as the nitrogen rate increases the utilization of the added nitrogen is decreased (Brégard et al., 2000; Delogu et al., 1998; Giambalvo et al., 2010). Summer nitrogen applications also decreased FUE in the first year at LCB by 32% and three year cumulative at Chickasha by 27%. Wheat FUE from the third year was increased due to the increased N application in the previous summer, which is the only instance in the study where FUE was increased due to N application. While these findings are unique in this study they are similar to Thomason et al. (2000) who found increased FUE in wheat forage production with increased N rate.

Interaction of wheat nitrogen and summer nitrogen applications cause decreases in FUE for total production of Chickasha 2018-2019 and 2019-2020, and the cumulative system FUE after two years for both locations. The interaction of a low 67 kg N ha^{-1} pre-plant rate followed by no summer nitrogen had the highest FUE values. This is due to the increasing nitrogen application rates that occur when summer N and wheat nitrogen are interacting. This interaction is no different than seen previously where lower rates of N result in greater efficiency. A fallow period resulted in greater FUE in the 2019-2020 and 2020-2021 wheat seasons at LCB, while the use of a cowpea summer forage crop, mixed or monoculture, increased FUE in 2018-2019 at LCB, 2019-2020 at Chickasha, and for the cumulative system after two years and three years at LCB.

A three-way interaction between wheat N application, summer N application, and summer cropping method was observed for FUE in the total of year two production. At this time the greatest FUE, by 46% or more, was achieved with a 67 kg N ha^{-1} pre-plant wheat application, followed by a mix species summer forage crop of crabgrass and cowpeas, with no summer N application. The lowest FUE combination was induced by the 135 kg N ha^{-1} followed by a fallow period that received a summer N application, which resulted in an FUE of 92%. This means there was 8% more fertilizer applied than was removed to produce the crop.

Low FUE values are similar to low NUE values in how they represent an over-fertilization of the crop (Omara et al., 2019; Raun & Johnson, 1999), while high FUE values represent the demand of the crop has not been met. Which results in the removal of N from the soil system to reach the crops maximum potential, for a forage crop maximum potential is not only decided by biomass production but also forage quality.

The most common quality factor that is influenced by N removed from the system is crude protein concentration..

Crude protein concentration of the wheat forage production was similar across most harvests and both locations, where CP was increased by the application of 135 kg N ha^{-1} at pre-plant in the first harvest of 2018-2019 and 2019-2020 at both locations. While in the final harvest of 2018-2019 at both locations and LCB 2019-2020 the CP was increased by the 135 kg N ha^{-1} at pre-plant application but increased greater when the additional 67 kg N ha^{-1} was delayed to until top-dress. In the final harvest of both locations the CP was only significant for LCB which resulted in increased CP with the split application compared to either pre-plant rate, while at Chickasha the trend increased with rate regardless of method of application.

Crude protein levels in the first harvest of the 2019-2020 wheat growing season were decreased by 0.6% and 0.8% for LCB and Chickasha, respectively, when summer N was applied. This decreased CP level is due to increased biomass production from the additional N resulting in greater dilution. With an opposing non-significant trend in the following harvest at Chickasha. Lake Carl Blackwell CP were also decreased in the first harvest in 2019-2020 by 1.1% when a summer forage crop containing crabgrass was used in, as well as following the same trend in the final harvest of that year. Similar finds were reported by Horn et al. (2021) who found the increase in summer crop production decreased the CP of the subsequent wheat crop in Oklahoma.

Summer forage crude protein concentrations were only influenced by treatments at Lake Carl Blackwell, where both summer forage crop and summer nitrogen had influence both years, as well as a trend of interaction in the 2020 summer. Summer N application decreased the CP of the summer crops in both years at LCB. However, the use of cowpeas resulted in the greatest CP when planted as monoculture in 2019 and both monoculture and mixed in 2020. Although, the increase in CP concentration reported before (Horn et al., 2021), this studies results show similar to others as well where the mixture of cowpeas and a grass also resulted in greater CP than a grass alone (Islam et al., 2018).

Total digestible nutrients and acid detergent fiber were influenced by treatments similarly in each harvest. Which can be attributed to the fact that TDN is calculated using the ADF value (Zhang & Henderson, 2016), because ADF represents the slowly digestible portion of forage (Rocateli & Zhang, 2015). Therefore these variables will be discussed together. At Chickasha TDN and ADF were only significantly impacted by wheat nitrogen application in the final harvest of the 2018-2019 wheat growing season, with a trend of influence by summer N in the final harvest of the following year (2019-2020). This is similar to other results which show limited response to treatments at the Chickasha location. Lake Carl Blackwell had more response to treatments than observed at Chickasha but the responses are similar.

The increase in N application such as the high rate in the first harvest of LCB 2018-2019 and LCB 2019-2020 and the application of top-dress N in the final harvest of Chickasha in 2019-2020 increased the ADF which resulted in lower TDN. The final harvest of 2018-2019 at LCB had a trend of similar decrease. The addition of summer N also led to higher ADF and lower TDN values in the first harvest of 2019-2020 with a similar trend in the final harvest of 2019-2020. The degradation of TDN and increased content of ADF has been reported to increase with increased N application rate in several other forage grasses such as bahiagrass and stargrass (*Cynodon nlemfuensis*) (Johnson et al., 2001), switchgrass (Guretzky et al., 2011), and small grain forages such as tritcale (*xTritcosecale*) (Obour et al., 2020) , and oats (*Avena sativa*) (Obour et al., 2019).

When crabgrass was used as a monoculture forage crop TDN was decreased and ADF was increased in the first summer harvest at the LCB location. While the cowpea forage crop, monoculture or mixed, decreased the ADF and increased TDN when no N was applied in the second summer at LCB. This combination resulted in increased ADF and decreased TDN in the subsequent wheat crop at this location. This interesting interaction influence that carried over could be due to decreased N availability to the cowpeas which resulted in greater N fixation and less exploitation of soil N (Haque & Lupwayi, 2000), leaving a greater N concentration in the subsequent wheat crop, especially after microbial breakdown. Although, ADF and TDN are important as they presents the slowly digestible portion, and total digestibility of the forage, respectively. TDN plays a role in the calculation of other forage quality parameters such as net energy values.

Net energy values represent the amount of harvest forage that will be available for the required goal of the forage, such as maintenance (NE_m), lactation (NE_l), and gain (NE_g). These values resulted in similar treatment responses as ADF and TDN since they are calculated using TDN (Zhang & Henderson, 2016). Similar to other results the Chickasha location had minimal significance of influence on net energy. Where the wheat N application influenced the net energy values in 2018-2019 harvest 1 at LCB and harvest 2 at Chickasha, and 2019-2021 harvest 1 at LCB. Summer nitrogen application and summer crop influenced the net energy of 2019-2020 harvest 1 at LCB with their interaction influencing the 2020 summer and 2020-2021 harvests at LCB.

The use of a higher rate of N of 135 kg N ha^{-1} at pre-plant increased all net energy values in the first harvest of 2018-2019 and 2019-2020 at LCB with a trend of increase for NE_m and NE_g in the final harvest of 2018-2019 LCB. While interestingly the final harvest of 2028-2019 at Chickisha, which is the only season with significant response of net energy, had a decrease in NE_m and NE_l due to the top-dress application of the split application. Net energy for gain had a trend to decrease due to rate at this harvest as well. This decrease in net energy also present in the harvest of the second summer at LCB, where all three net energy parameters were decreased due to the addition of N to the summer crops, with NE_l and NE_g having a similar trend of decrease. The influence of nitrogen rate observed in this study are dissimilar to other studies which have shown no influence of N rate on forage net energy values (Marsalis et al., 2010; Tang et al., 2018).

Wheat following a fallow period had the greatest net energy response in the first harvest of 2019-2020. The use of cowpeas, monoculture or mixed, with no N application resulted in the greatest net energy response in the 2020 summer at LCB, while in the following wheat harvest it resulted in the lowest net energy values. The increase in summer forage net energy is similar to that reported by (Sher et al., 2017) who observed decreased NE_l values as N application increased beyond the no N control. A decrease in the net energy in the subsequent wheat due to the cowpea or mixed summer forage crop with no N application, can be tied to the reduction in TDN observed from the same treatment.

Conclusion

The first objective of this trial was to evaluate nitrogen management strategies of a continuous forage production system. In this study it was found that the use of an increased pre-plant rate or split application of N would increase the biomass production and CP content of wheat forage. Similarly, summer forage biomass and CP was also increased with the application of N. With greater N uptake occurring as observed in this study by increasing N applications, the quality of forage had a tendency to fluctuate.

Where the TDN tended to decrease as the N rate increased, but net energy measurements were not always impacted similarly. The second objective of the study was to evaluate the influence of a fallow replacement crop in a continuous forage production system. This study was unable to establish a full stand of pearl millet in any site year due to the extreme drought conditions and invasive species competition. Therefore, the project concludes it was not feasible in the locations of the research, its value beyond the study cannot be extrapolated. Reductions in wheat biomass yields were observed when summer forage was implements, however this loss was outweighed by the increased total biomass produced by the system, as a whole.

This work indicates that winter wheat forage producers in the central Great Plains should consider planting a summer forage such as cowpea due to the increased biomass production that this study noted. Also producers in a graze-out wheat system would be benefit from the split application of nitrogen opposed to the all pre-plant method. While N applications to the summer crop increase biomass production, it decreased the quality of the summer forage. Further work is needed to evaluate this interaction of forage quality and biomass production. The use of a summer forage crop can be a challenge for the region of this study, and further work would be needed to evaluate the ideal summer forage species for this production region.

Table 12. Dates of planting, fertilization, and harvest for each crop season of each year at Chickasha and Lake Carl Blackwell.

Location	Crop	Event	2018-2019	2019-2020	2020-2021
Chickasha	Winter Wheat	Pre-Plant Fertilization	9/20/2018	9/19/2020	9/29/2021
		Planting	9/20/2018	9/19/2020	9/29/2021
		Harvest 1	3/6/2019	2/27/2020	--
		Top-Dress Fertilization	3/19/19	2/27/2020	3/15/2021
		Harvest 2	4/26/2019	4/21/2020	4/22/2021
	Summer Crops	Planting	7/2/2019	5/20/2020	--
		Fertilization	7/11/2019	6/11/2020	--
		Harvest	--	8/28/2020	--
Lake Carl Blackwell	Winter Wheat	Pre-Plant Fertilization	9/17/2018	9/10/2019	9/17/2020
		Planting	9/17/2018	9/16/2019	9/17/2020
		Harvest 1	12/17/2018	3/5/2020	--
		Top-Dress Fertilization	3/22/2019	3/6/2020	3/21/2021
		Harvest 2	5/14/2019	4/16/2020	4/20/2021
	Summer Crops	Planting	6/3/2019	5/18/2020	--
		Fertilization	6/13/2019	6/10/2020	--
		Harvest	8/22/2019	8/21/2020	--

*Table 13. Average daily temperature (*C) and monthly total rainfall (mm) each month for each year at Chickasha and Lake Carl Blackwell locations*

	Chickasha						Lake Carl Blackwell					
	2018-2019		**2019-2020**		**2020-2021**		**2018-2019**		**2019-2020**		**2020-2021**	
Month	***°C***	***mm***	***°C***	***mm***	***°C***	***mm***	***°C***	***mm***	***°C***	***mm***	***°C***	***mm***
September	22.3	130.3	26.5	7.9	19.9	1.8	21.9	27.7	25.9	163.6	18.8	16
	(18)*		(9)*		(9)*		(21)*		(28)*		(21)*	
October	15.6	144.5	14	81	14.2	99.8	14.7	181.6	13	53.6	13.5	125
	(31)		(31)		(31)		(31)		(31)		(31)	
November	6.9	12.7	7.4	33.8	11.8	22.9	5.5	11.7	6.9	58.7	10.8	26.9
	(30)		(30)		(30)		(30)		(30)		(30)	
December	4.6	124.2	5.7	17	4.9	67.8	3.7	75.2	5	22.1	3.8	72.4
	(31)		(31)		(31)		(31)		(31)		(31)	
January	3.4	46.5	6	78	4.3	45	2.5	58.2	4.5	70.1	3.2	72.9
	(31)		(31)		(31)		(31)		(31)		(31)	
February	4.6	14	5.6	24.1	-0.6	25.4	3	47.5	4.9	21.6	-1.5	13.7
	(28)		(29)		(28)		(28)		(29)		(28)	
March	8.6	79.2	13.2	122.4	12.5	35.6	7.8	55.1	12.2	127	11.9	79
	(31)		(31)		(31)		(31)		(31)		(31)	
April	16.3	148.3	14.6	54.4	13	38.9	15.7	111	14.1	20.8	13	64
	(30)		(30)		(22)*		(30)		(30)		(20)*	
May	20	218.7	20.2	128.8			19.2	413.5	18.8	62.2		
	(31)		(31)				(31)		(31)			
June	24.3	138.2	25.6	56.4			24.1	102.6	26.1	57.9		
	(30)		(30)				(30)		(30)			
July	27.6	0.8	28	68.6			26.9	33.3	27.3	152.7		
	(31)		(31)				(31)		(31)			
August	30	14.7	26.5	40.1			28.1	77	24.9	51.3		
	(22)*		(28)*				(22)*		(21)*			
Year		1072.1		712.5		337.1		1194.3		3250.2		470

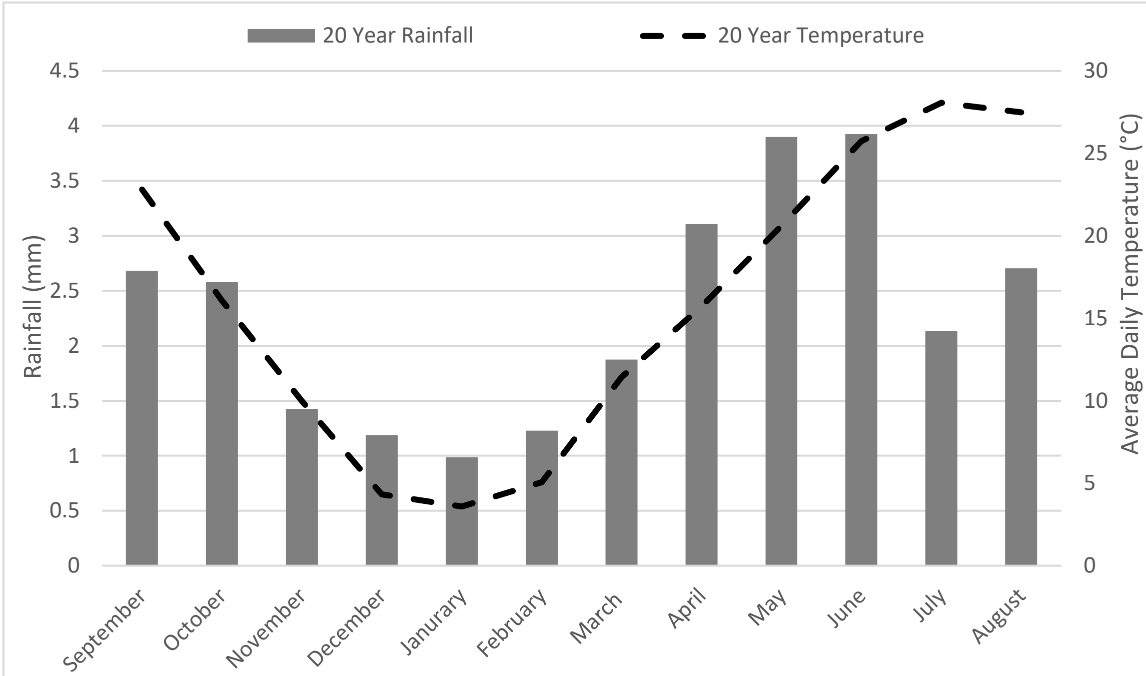

Figure 3. Monthly rainfall amounts (mm) and average daily temperatures (°C) at Chickasha for 20 years (7/1/2001 – 7/1/ 2021).

Table 14. Winter wheat forage harvest yield and quality results from Chickasha 2018-2019 first harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NEM), lactation (NEL), and gain (NEG). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments full planting rate of cowpea (CP1x), half planting rate of cowpea (CP0.5x), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**Dry Matter** *(Mg ha^{-1})*	**CP** *(%)*	**ADF** *(%)*	**TDN** *(%)*	**NE_M** *(%)*	**NE_L** *(%)*	**NE_G** *(%)*	**N Uptake** *(kg ha^{-1})*
67	**0**	**CP_{1x}**	4.2	14.6	22.1	71.8	0.77	0.74	0.49	95.9
		$CP_{0.5x}$	4.9	15.2	22.5	71.3	0.76	0.74	0.49	120.9
		F	4.6	14.9	21.9	71.9	0.77	0.75	0.49	110.0
	34	**CP_{1x}**	3.5	14.4	22.0	71.8	0.77	0.75	0.49	79.3
		$CP_{0.5x}$	6.1	14.9	22.0	71.8	0.77	0.75	0.49	145.4
		F	4.8	14.3	22.2	71.6	0.77	0.74	0.49	109.6
135	**0**	**CP_{1x}**	4.4	17.2	21.9	71.8	0.77	0.75	0.49	114.8
		$CP_{0.5x}$	4.8	14.9	22.4	71.5	0.77	0.74	0.49	114.3
		F	4.4	16.3	22.5	71.4	0.76	0.74	0.48	113.9
	34	**CP_{1x}**	2.1	16.4	21.8	71.9	0.77	0.75	0.49	57.4
		$CP_{0.5x}$	4.0	16.3	21.2	72.4	0.78	0.75	0.50	108.0
		F	5.0	16.2	23.3	70.8	0.75	0.74	0.48	129.0
Split	**0**	**CP_{1x}**	3.9	14.5	22.0	71.8	0.77	0.74	0.49	90.4
		$CP_{0.5x}$	4.6	14.9	23.7	70.4	0.75	0.73	0.48	109.8
		F	5.4	14.4	22.5	71.3	0.76	0.74	0.48	125.1
	34	**CP_{1x}**	3.4	14.9	22.8	71.2	0.76	0.74	0.48	84.0
		$CP_{0.5x}$	3.6	14.0	23.0	71.0	0.76	0.74	0.48	83.0
		F	5.6	14.9	22.0	71.8	0.77	0.75	0.49	134.8
		Wheat N	0.5378	<0.0001	0.4868	0.4922	0.4123	0.4186	0.5628	0.9964
		Summer Crop	--	--	--	--	--	--	--	--
		Summer N	--	--	--	--	--	--	--	--
		WN x SC	--	--	--	--	--	--	--	--
		WN x SN	--	--	--	--	--	--	--	--
		SN x SC	--	--	--	--	--	--	--	--
		WN x SC x SN	--	--	--	--	--	--	--	--

Table 15. Winter wheat forage harvest yield and quality results from Chickasha 2018-2019 second harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NE_M), lactation (NE_L), and gain (NE_G). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments full planting rate of cowpea (CP_{1x}), half planting rate of cowpea ($CP_{0.5x}$), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**Dry Matter** *(Mg ha^{-1})*	**CP** *(%)*	**ADF** *(%)*	**TDN** *(%)*	**NE_M** *(%)*	**NE_L** *(%)*	**NE_G** *(%)*	**N Uptake** *(kg ha^{-1})*
67	**0**	**CP_{1x}**	7.8	8.5	34.6	62.0	0.63	0.64	0.36	106.4
		$CP_{0.5x}$	7.4	8.6	35.5	61.3	0.61	0.63	0.35	101.8
		F	8.0	8.8	35.1	61.6	0.62	0.63	0.36	112.1
	34	**CP_{1x}**	7.4	8.5	36.7	60.3	0.60	0.62	0.34	100.1
		$CP_{0.5x}$	7.3	8.7	35.8	61.0	0.61	0.63	0.35	100.5
		F	7.7	8.8	35.7	61.1	0.61	0.63	0.35	108.7
135	**0**	**CP_{1x}**	7.7	10.5	35.9	60.9	0.61	0.63	0.35	130.4
		$CP_{0.5x}$	8.0	9.6	34.9	61.7	0.62	0.64	0.36	124.0
		F	9.4	8.8	36.1	60.8	0.61	0.62	0.35	130.3
	34	**CP_{1x}**	8.2	9.2	35.8	61.0	0.61	0.63	0.35	122.0
		$CP_{0.5x}$	8.4	9.3	35.6	61.2	0.61	0.63	0.35	124.9
		F	8.5	9.6	35.2	61.5	0.62	0.63	0.36	130.8
Split	**0**	**CP_{1x}**	10.5	11.1	36.2	60.7	0.61	0.62	0.35	186.5
		$CP_{0.5x}$	10.1	9.8	37.3	59.9	0.60	0.61	0.34	159.5
		F	11.6	10.4	35.9	60.9	0.61	0.63	0.35	192.5
	34	**CP_{1x}**	8.6	10.9	36.4	60.5	0.60	0.62	0.34	148.8
		$CP_{0.5x}$	11.2	10.4	37.3	59.9	0.59	0.62	0.33	190.7
		F	9.0	10.9	35.6	61.2	0.61	0.63	0.35	153.9
		Wheat N	<0.0001	<0.0001	0.0293	0.0262	0.0404	0.0162	0.0626	<.0001
		Summer Crop	--	--	--	--	--	--	--	--
		Summer N	--	--	--	--	--	--	--	--
		WN x SC	--	--	--	--	--	--	--	--
		WN x SN	--	--	--	--	--	--	--	--
		SN x SC	--	--	--	--	--	--	--	--
		WN x SC x SN	--	--	--	--	--	--	--	--

Table 16. Winter wheat forage harvest yield and quality results from Chickasha 2019-2020 first harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NE_M), lactation (NE_L), and gain (NE_G). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments full planting rate of cowpea (CP_{1x}), half planting rate of cowpea ($CP_{0.5x}$), and fallow (F)

Wheat N *(kg ha⁻¹)*	**Summer N** *(kg ha⁻¹)*	**Summer Crop**	**Dry Matter** *(Mg ha⁻¹)*	**CP** *(%)*	**ADF** *(%)*	**TDN** *(%)*	**NE_M** *(%)*	**NE_L** *(%)*	**NE_G** *(%)*	**N Uptake** *(kg ha⁻¹)*
67	**0**	**CP_{1x}**	1.7	16.4	24.6	69.78	0.74	0.72	0.5	70.6
		$CP_{0.5x}$	2.6	17.2	24.0	70.25	0.75	0.73	0.5	73.6
		F	3.5	17.4	24.6	69.75	0.74	0.72	0.5	60.3
	34	**CP_{1x}**	2.2	15.9	24.1	70.15	0.74	0.73	0.5	50.2
		$CP_{0.5x}$	2.4	15.6	24.1	70.13	0.74	0.73	0.5	51.3
		F	2.8	16.2	25.5	69.00	0.73	0.72	0.5	60.0
135	**0**	**CP_{1x}**	2.9	19.1	24.6	69.78	0.74	0.72	0.5	95.5
		$CP_{0.5x}$	2.8	19.4	25.0	69.43	0.73	0.72	0.5	91.4
		F	3.3	18.6	25.0	69.40	0.73	0.72	0.5	89.6
	34	**CP_{1x}**	2.8	18.0	24.4	69.95	0.74	0.72	0.5	83.2
		$CP_{0.5x}$	3.5	18.6	23.7	70.50	0.75	0.73	0.5	52.7
		F	3.1	17.9	24.7	69.68	0.74	0.72	0.5	84.6
Split	**0**	**CP_{1x}**	2.5	16.1	25.8	68.83	0.73	0.71	0.5	75.5
		$CP_{0.5x}$	3.2	17.3	24.6	69.73	0.74	0.72	0.5	87.1
		F	3.9	17.6	24.7	69.66	0.74	0.72	0.5	80.9
	34	**CP_{1x}**	4.2	15.9	24.8	69.60	0.74	0.72	0.5	74.2
		$CP_{0.5x}$	2.3	16.8	22.8	71.10	0.76	0.74	0.5	64.0
		F	3.6	16.9	24.5	69.86	0.74	0.73	0.5	88.6
		Wheat N	0.261	<0.0001	0.9714	0.9707	0.9347	0.8601	0.7868	0.0005
		Summer Crop	0.8901	0.0045	0.2948	0.2874	0.286	0.3719	0.3437	0.0596
		Summer N	0.9238	0.6858	0.2295	0.2404	0.0984	0.2708	0.4077	0.5553
		WN x SC	--	--	--	--	--	--	--	--
		WN x SN	--	--	--	--	--	--	--	--
		SN x SC	--	--	--	--	--	--	--	--
		WN x SC x SN	--	--	--	--	--	--	--	--

Table 17. Winter wheat forage harvest yield and quality results from Chickasha 2019-2020 second harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NE_M), lactation (NE_L), and gain (NE_G). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments full planting rate of cowpea (CP_{1x}), half planting rate of cowpea ($CP_{0.5x}$), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**Dry Matter** *(Mg ha^{-1})*	**CP** *(%)*	**ADF** *(%)*	**TDN** *(%)*	**NE_M** *(%)*	**NE_L** *(%)*	**NE_G** *(%)*	**N Uptake** *(kg ha^{-1})*
67	**0**	**CP_{1x}**	5.9	9.5	34.0	62.43	0.63	0.64	0.4	90.6
		$CP_{0.5x}$	7.1	9.8	34.1	62.38	0.63	0.64	0.4	112.3
		F	6.1	9.4	35.1	61.58	0.62	0.63	0.4	92.1
	34	**CP_{1x}**	5.1	9.4	36.0	60.88	0.61	0.62	0.3	78.2
		$CP_{0.5x}$	8.1	10.1	36.5	60.48	0.60	0.62	0.3	128.6
		F	5.7	10.4	35.8	61.08	0.61	0.63	0.4	100.9
135	**0**	**CP_{1x}**	8.1	9.2	34.5	62.03	0.63	0.64	0.4	120.3
		$CP_{0.5x}$	6.9	9.4	34.1	62.33	0.63	0.64	0.4	104.5
		F	6.1	9.0	34.8	61.80	0.62	0.63	0.4	88.2
	34	**CP_{1x}**	4.8	10.5	34.8	61.83	0.62	0.63	0.4	82.3
		$CP_{0.5x}$	6.8	10.1	35.4	61.35	0.61	0.63	0.4	106.8
		F	5.6	9.7	34.6	61.96	0.63	0.64	0.4	87.9
Split	**0**	**CP_{1x}**	5.0	9.1	34.1	62.35	0.63	0.64	0.4	72.5
		$CP_{0.5x}$	5.8	9.5	36.1	60.80	0.61	0.62	0.3	87.1
		F	6.2	8.9	34.4	62.11	0.63	0.64	0.4	88.7
	34	**CP_{1x}**	6.3	9.6	36.2	60.75	0.61	0.62	0.3	97.0
		$CP_{0.5x}$	6.0	9.0	35.3	61.40	0.62	0.63	0.4	85.3
		F	6.4	9.2	35.3	61.41	0.62	0.63	0.4	94.7
		Wheat N	0.9126	0.1261	0.3309	0.3472	0.4017	0.3874	0.5045	0.5372
		Summer Crop	0.7915	0.0891	0.0757	0.0817	0.1269	0.0982	0.0827	0.8175
		Summer N	0.3863	0.5533	0.3710	0.3740	0.4081	0.4031	0.3202	0.6327
		WN x SC	--	--	--	--	--	--	--	--
		WN x SN	--	--	--	--	--	--	--	--
		SN x SC	--	--	--	--	--	--	--	--
		WN x SC x SN	--	--	--	--	--	--	--	--

Table 18. Winter wheat forage harvest yield and quality results from Chickasha 2020 summer Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NE_M), lactation (NE_L), and gain (NE_G). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments full planting rate of cowpea (CP_{1x}), half planting rate of cowpea ($CP_{0.5x}$), and fallow (F)

Wheat N *(kg ha^{-1})*	Summer N *(kg ha^{-1})*	Summer Crop	Dry Matter *(Mg ha^{-1})*	CP *(%)*	ADF *(%)*	TDN *(%)*	NE_M *(%)*	NE_L *(%)*	NE_G *(%)*	N Uptake *(kg ha^{-1})*
67	0	CP_{1x}	2.7	19.3	31.2	64.57	0.66	0.67	0.4	81.9
		$CP_{0.5x}$	1.5	17.1	30.6	65.07	0.67	0.67	0.4	42.2
		F								
	34	CP_{1x}	2.6	18.2	32.3	63.70	0.65	0.65	0.4	77.7
		$CP_{0.5x}$	1.8	17.9	32.6	63.47	0.65	0.65	0.4	50.1
		F								
135	0	CP_{1x}	2.3	18.0	31.1	64.70	0.67	0.67	0.4	64.8
		$CP_{0.5x}$	1.5	17.6	28.1	67.05	0.70	0.69	0.4	43.8
		F								
	34	CP_{1x}	3.0	19.7	28.9	66.33	0.69	0.68	0.4	91.1
		$CP_{0.5x}$	2.0	18.0	31.6	64.30	0.66	0.66	0.4	53.8
		F								
Split	0	CP_{1x}	2.2	18.7	30.9	64.85	0.67	0.67	0.4	66.7
		$CP_{0.5x}$	2.2	18.4	28.8	66.50	0.69	0.69	0.4	66.0
		F								
	34	CP_{1x}	3.4	17.8	33.3	62.93	0.64	0.65	0.4	94.1
		$CP_{0.5x}$	2.3	17.1	33.1	63.13	0.64	0.65	0.4	64.9
		F								
		Wheat N	0.2864	0.9644	0.3808	0.3756	0.3604	0.4254	0.3646	0.3309
		Summer Crop	0.1011	0.8920	0.0990	0.0975	0.1055	0.0890	0.1122	0.1286
		Summer N	0.6173	0.4866	0.7286	0.7276	0.8086	0.7510	0.7387	0.6868
		WN x SC	0.0053	0.2073	0.5721	0.5552	0.5815	0.5617	0.6850	0.0015
		WN x SN	1.0000	0.8480	0.9879	0.9923	0.9635	0.9735	0.9475	0.9456
		SN x SC	0.4735	0.8582	0.2625	0.2710	0.2588	0.2908	0.2956	0.4488
		WN x SC x SN	0.6249	0.6612	0.6122	0.6184	0.6149	0.6932	0.6576	0.5469

Table 19. Winter wheat forage harvest yield and quality results from Chickasha 2020-2021 harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NE_M), lactation (NE_L), and gain (NE_G). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments full planting rate of cowpea (CP_{1x}), half planting rate of cowpea ($CP_{0.5x}$), and fallow (F)

Wheat N	Summer N	Summer Crop	Dry Matter	CP	ADF	TDN	NE_M	NE_L	NE_G	N Uptake
(kg ha⁻¹)	*(kg ha⁻¹)*		*(Mg ha⁻¹)*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*	*(kg ha⁻¹)*
67	**0**	**CP_{1x}**	6.6	10.4	32.7	63.38	0.65	0.65	0.4	110.3
		$CP_{0.5x}$	6.0	9.9	32.9	63.25	0.65	0.65	0.4	95.3
		F	6.2	10.2	32.8	63.38	0.65	0.65	0.4	100.3
	34	**CP_{1x}**	6.3	10.1	32.3	63.73	0.65	0.66	0.4	101.7
		$CP_{0.5x}$	6.8	9.9	32.3	63.78	0.65	0.66	0.4	107.3
		F	6.1	9.9	32.3	63.73	0.65	0.66	0.4	97.6
135	**0**	**CP_{1x}**	8.3	9.9	33.4	62.93	0.64	0.65	0.4	132.6
		$CP_{0.5x}$	8.4	10.2	32.2	63.83	0.65	0.66	0.4	135.0
		F	7.7	11.3	32.8	63.34	0.65	0.65	0.4	139.4
	34	**CP_{1x}**	7.9	9.7	32.8	63.38	0.64	0.65	0.4	122.8
		$CP_{0.5x}$	8.7	10.8	32.9	63.25	0.64	0.65	0.4	147.7
		F	8.0	11.0	32.7	63.41	0.65	0.65	0.4	139.3
Split	**0**	**CP_{1x}**	6.8	11.1	32.9	63.28	0.64	0.65	0.4	119.7
		$CP_{0.5x}$	7.2	10.3	32.0	63.98	0.66	0.66	0.4	117.2
		F	7.0	11.3	32.1	63.86	0.65	0.66	0.4	127.0
	34	**CP_{1x}**	7.1	10.8	32.4	63.68	0.65	0.66	0.4	122.4
		$CP_{0.5x}$	7.2	12.3	33.2	63.10	0.64	0.65	0.4	144.4
		F	7.6	11.0	33.0	63.23	0.64	0.65	0.4	134.2
		Wheat N	<0.0001	0.0885	0.5709	0.5708	0.5702	0.7223	0.7169	<0.0001
		Summer Crop	0.4000	1.0000	0.9075	0.9356	0.9270	0.9143	0.8498	0.4101
		Summer N	0.8355	0.7292	0.0961	0.0958	0.2029	0.1850	0.0538	0.5177
		WN x SC	0.8128	0.3329	0.8288	0.8042	0.5644	0.9569	0.9172	0.7253
		WN x SN	0.8152	0.2285	0.9883	0.9899	0.8785	0.9796	0.9578	0.8040
		SN x SC	0.8855	0.1737	0.2097	0.2383	0.2549	0.4700	0.1470	0.3413
		WN x SC x SN	0.7568	0.7982	0.8212	0.8230	0.8281	0.7604	0.9166	0.8951

Table 20. Cumulative winter wheat forage harvest yield in Mg ha^{-1} from each year and system total at Chickasha. P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha^{-1} at pre-plant, 135 kg ha^{-1} at pre-plant, and a split application of 67 kg N ha^{-1} pre-plant and 67 kg N ha^{-1} at top-dress. Summer crop treatments full planting rate of cowpea (CP_{1x}), half planting rate of cowpea ($CP_{0.5x}$), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**2018 - 2019** *(Mg ha^{-1})*	**2019 - 2020** *(Mg ha^{-1})*	**2020 - 2021** *(Mg ha^{-1})*	**Total** *(Mg ha^{-1})*
		CP_{1x}	12.1	7.6	6.6	26.3
	0	**$CP_{0.5x}$**	12.3	9.6	6.0	28.0
67		**F**	12.6	9.6	6.2	28.4
		CP_{1x}	10.8	7.3	6.3	24.5
	34	**$CP_{0.5x}$**	13.4	10.5	6.8	30.8
		F	12.5	8.6	6.1	27.2
		CP_{1x}	12.1	11.0	8.3	31.5
	0	**$CP_{0.5x}$**	12.8	9.7	8.4	30.9
135		**F**	13.7	9.4	7.7	30.9
		CP_{1x}	10.4	7.6	7.9	25.9
	34	**$CP_{0.5x}$**	12.4	10.3	8.7	31.4
		F	13.5	8.7	8.0	30.2
		CP_{1x}	14.4	7.5	6.8	28.7
	0	**$CP_{0.5x}$**	14.8	9.0	7.2	30.9
Split		**F**	17.1	10.1	7.0	34.2
		CP_{1x}	12.0	10.4	7.1	29.6
	34	**$CP_{0.5x}$**	14.8	8.4	7.2	30.4
		F	13.5	10.0	7.6	31.0
		Wheat N	0.0038	0.8401	<0.0001	0.0006
		Summer Crop	--	0.7558	0.3993	0.1362
		Summer N	--	0.6063	0.8384	0.7721
		WN x SC	--	0.5442	0.8119	0.0055
		WN x SN	--	--	0.8143	0.5672
		SN x SC	--	--	0.8828	0.2894
		WN x SC x SN	--	--	0.7547	0.6409

Table 21. Cumulative winter wheat N uptake in kg ha^{-1} from each year and system total at Chickasha. P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha^{-1} at pre-plant, 135 kg ha^{-1} at pre-plant, and a split application of 67 kg N ha^{-1} pre-plant and 67 kg N ha^{-1} at top-dress. Summer crop treatments full planting rate of cowpea (CP_{1x}), half planting rate of cowpea ($CP_{0.5x}$), and fallow (F)

Wheat N (kg ha^{-1})	Summer N (kg ha^{-1})	Summer Crop	2018 - 2019 (kg ha^{-1})	2019 - 2020 (kg ha^{-1})	2020 - 2021 (kg ha^{-1})	Total (kg ha^{-1})
67	0	CP_{1x}	202.4	161.2	110.3	110.3
		$CP_{0.5x}$	222.7	249.6	95.3	95.3
		F	222.1	248.9	100.3	100.3
	34	CP_{1x}	179.4	201.1	101.7	101.7
		$CP_{0.5x}$	245.9	275.6	107.3	107.3
		F	218.3	244.6	97.6	97.6
135	0	CP_{1x}	245.3	274.9	132.6	132.6
		$CP_{0.5x}$	238.3	267.1	135.0	135.0
		F	244.2	273.7	139.4	139.4
	34	CP_{1x}	179.4	201.0	122.8	122.8
		$CP_{0.5x}$	232.8	261.0	147.7	147.7
		F	259.8	291.2	139.3	139.3
Split	0	CP_{1x}	276.9	310.3	119.7	119.7
		$CP_{0.5x}$	269.3	301.8	117.2	117.2
		F	317.6	355.9	127.0	127.0
	34	CP_{1x}	232.7	260.9	122.4	122.4
		$CP_{0.5x}$	273.7	306.8	144.4	144.4
		F	269.5	302.1	134.2	134.2
		Wheat N	0.0002	0.4208	<0.0001	<0.0001
		Summer Crop	--	0.2682	0.4102	0.2479
		Summer N	--	0.4247	0.5177	0.8117
		WN x SC	--	0.4307	0.7253	0.1286
		WN x SN	--	--	0.804	0.3017
		SN x SC	--	--	0.3413	0.3694
		WN x SC x SN	--	--	0.8952	0.5629

Table 22. Cumulative forage harvest yield in Mg ha^{-1} from each year that included a summer crop and two and three year totals at Chickasha. P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha^{-1} at pre-plant, 135 kg ha^{-1} at pre-plant, and a split application of 67 kg N ha^{-1} pre-plant and 67 kg N ha^{-1} at top-dress. Summer crop treatments full planting rate of cowpea (CP$_{1x}$), half planting rate of cowpea (CP$_{0.5x}$), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**2018 - 2019** *(Mg ha^{-1})*	**2018 - 2020** *(Mg ha^{-1})*	**2018 - 2020** *(Mg ha^{-1})*	**2018 - 2021** *(Mg ha^{-1})*
67	**0**	**CP$_{1x}$**	12.1	9.6	21.7	28.3
		CP$_{0.5x}$	12.3	10.8	23.1	29.2
		F	12.6	9.6	22.2	28.4
	34	**CP$_{1x}$**	10.8	9.3	20.1	26.4
		CP$_{0.5x}$	13.4	11.8	25.2	32.1
		F	12.5	8.6	21.0	27.2
135	**0**	**CP$_{1x}$**	12.1	12.7	24.8	33.2
		CP$_{0.5x}$	12.8	11.2	24.0	32.4
		F	13.7	9.4	23.1	30.9
	34	**CP$_{1x}$**	10.4	9.8	20.2	28.1
		CP$_{0.5x}$	12.4	12.2	24.7	33.4
		F	13.5	8.7	22.2	30.2
Split	**0**	**CP$_{1x}$**	14.4	9.8	24.2	30.9
		CP$_{0.5x}$	14.8	10.6	25.4	32.5
		F	17.1	10.1	27.2	34.2
	34	**CP$_{1x}$**	12.0	13.9	25.9	33.0
		CP$_{0.5x}$	14.8	10.1	24.9	32.2
		F	13.5	10.0	23.5	31.0
		Wheat N	0.0032	0.4982	0.0015	<0.0001
		Summer Crop	0.0675	0.8538	0.0976	0.1932
		Summer N	0.236	0.4877	0.7719	0.8345
		WN x SC	--	0.0345	0.0297	0.0248
		WN x SN	--	0.5881	0.6934	0.5784
		SN x SC	--	0.6000	0.2465	0.2514
		WN x SC x SN	--	0.4612	0.4922	0.4736

Table 23. Cumulative forage N uptake in kg ha⁻¹ from each year that included a summer crop and two and three year totals at Chickasha. P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha⁻¹ at pre-plant, 135 kg ha⁻¹ at pre-plant, and a split application of 67 kg N ha⁻¹ pre-plant and 67 kg N ha⁻¹ at top-dress. Summer crop treatments full planting rate of cowpea (CP_{1x}), half planting rate of cowpea ($CP_{0.5x}$), and fallow (F)

Wheat N *(kg ha⁻¹)*	**Summer N** *(kg ha⁻¹)*	**Summer Crop**	**2018 - 2019** *(kg ha⁻¹)*	**2018 - 2020** *(kg ha⁻¹)*	**2018 - 2020** *(kg ha⁻¹)*	**2018 - 2021** *(kg ha⁻¹)*
67	**0**	**CP_{1x}**	202.4	222.6	425.0	535.3
		$CP_{0.5x}$	222.7	217.6	440.3	535.6
		F	222.1	152.4	374.5	474.9
	34	**CP_{1x}**	179.4	186.7	366.1	467.8
		$CP_{0.5x}$	245.9	217.4	463.3	570.6
		F	218.3	161.0	379.2	476.8
135	**0**	**CP_{1x}**	245.3	264.5	509.8	642.3
		$CP_{0.5x}$	238.3	239.7	478.0	613.0
		F	244.2	177.8	422.0	561.3
	34	**CP_{1x}**	179.4	233.8	413.2	536.0
		$CP_{0.5x}$	232.8	213.2	446.0	593.7
		F	259.8	172.5	432.3	571.6
Split	**0**	**CP_{1x}**	276.9	214.7	491.6	611.2
		$CP_{0.5x}$	269.3	223.7	493.0	610.2
		F	317.5	169.6	487.2	614.2
	34	**CP_{1x}**	232.7	265.4	498.1	620.6
		$CP_{0.5x}$	273.7	198.0	471.7	616.2
		F	269.5	183.3	452.8	587.0
		Wheat N	0.0002	0.1813	0.0968	<0.0001
		Summer Crop	0.1944	0.7812	0.2635	0.3886
		Summer N	0.511	0.4916	0.8699	0.8791
		WN x SC	--	<.0001	0.1786	0.1857
		WN x SN	--	0.3391	0.4163	0.4024
		SN x SC	--	0.8044	0.6962	0.5394
		WN x SC x SN	--	0.6266	0.6327	0.5147

Table 24. Overall fertilizer use efficiency (FUE) from each year that included a summer and two and three year totals at Chickasha. P-values represent the significance of each variable and all interactions. FUE values less than 100% shows less N was taken up than applied by fertilizer. Wheat N treatments are 67 kg N ha^{-1} at pre-plant, 135 kg ha^{-1} at pre-plant, and a split application of 67 kg N ha^{-1} pre-plant and 67 kg N ha^{-1} at top-dress. Summer crop treatments full planting rate of cowpea (CP_{1x}), half planting rate of cowpea ($CP_{0.5x}$), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**2018 - 2019** *(%)*	**2018 - 2020** *(%)*	**2018 - 2020** *(%)*	**2018 - 2021** *(%)*
67	**0**	**CP_{1x}**	301	331	316	265
		$CP_{0.5x}$	331	324	327	265
		F	330	227	278	235
	34	**CP_{1x}**	178	185	181	199
		$CP_{0.5x}$	244	216	230	242
		F	216	160	188	203
135	**0**	**CP_{1x}**	182	197	189	159
		$CP_{0.5x}$	177	178	178	152
		F	182	132	157	139
	34	**CP_{1x}**	107	139	123	123
		$CP_{0.5x}$	138	127	133	136
		F	155	103	129	131
Split	**0**	**CP_{1x}**	206	160	183	151
		$CP_{0.5x}$	200	166	183	151
		F	236	126	181	152
	34	**CP_{1x}**	138	158	148	142
		$CP_{0.5x}$	163	118	140	141
		F	160	109	135	134
		Wheat N	<0.0001	<0.0001	<0.0001	<0.0001
		Summer Crop	<0.0001	<0.0001	<0.0001	<0.0001
		Summer N	0.0104	0.0036	0.0005	0.1204
		WN x SC	--	<.0001	0.0780	0.0742
		WN x SN	--	0.1590	0.2183	0.1577
		SN x SC	--	0.3998	0.5697	0.4447
		WN x SC x SN	--	0.6958	0.8073	0.632

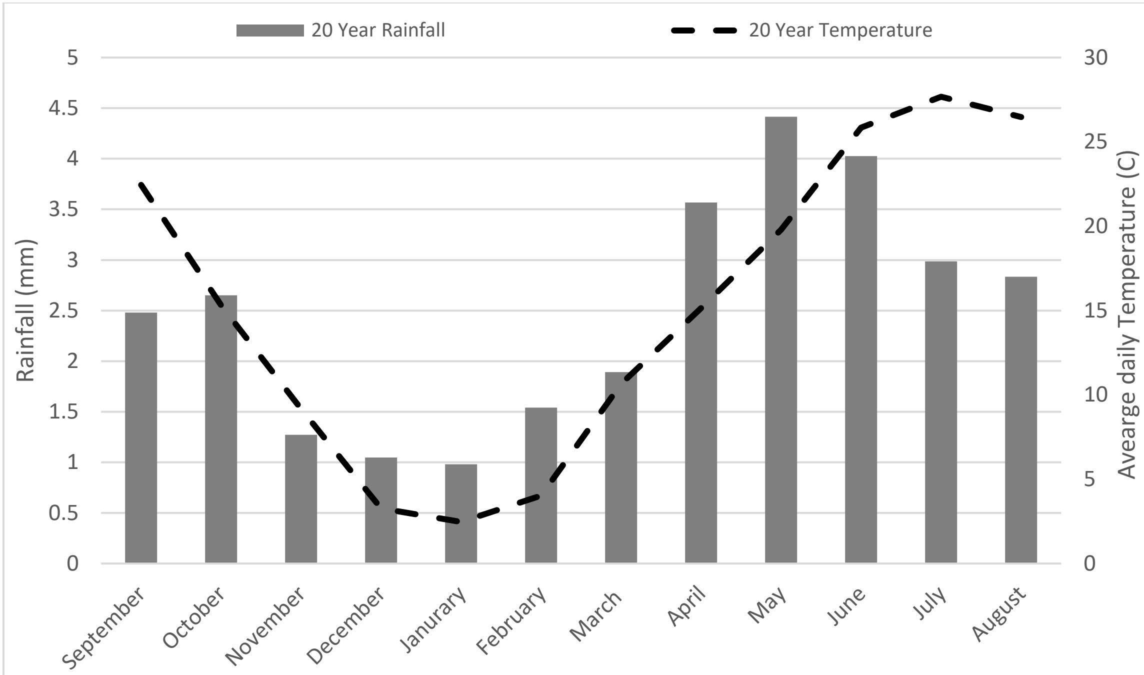

Figure 4. Monthly rainfall amounts (mm) and average daily temperatures (°C) at Lake Carl Blackwell for 20 years.

Table 25. Winter wheat forage harvest yield and quality results from LCB 2018-2019 first harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NEM), lactation (NEL), and gain (NEG). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N *(kg ha⁻¹)*	**Summer N** *(kg ha⁻¹)*	**Summer Crop**	**Dry Matter** *(Mg ha⁻¹)*	**CP** *(%)*	**ADF** *(%)*	**TDN** *(%)*	**NE_M** *(%)*	**NE_L** *(%)*	**NE_G** *(%)*	**N Uptake** *(kg ha⁻¹)*
67	**0**	**CG**	1.2	10.8	28.1	67.0	0.70	0.69	0.43	20.7
		CG-CP	1.3	10.9	27.5	67.5	0.71	0.70	0.44	22.8
		CP	1.5	11.9	26.2	68.5	0.72	0.71	0.45	27.8
		F	1.4	10.7	27.8	67.2	0.70	0.70	0.43	23.9
	34	**CG**	1.7	9.9	26.2	68.6	0.72	0.71	0.45	26.9
		CG-CP	1.5	10.6	25.8	68.8	0.73	0.71	0.45	25.2
		CP	1.5	11.1	28.4	66.8	0.70	0.69	0.43	26.1
		F	1.2	11.4	27.2	67.8	0.71	0.70	0.44	22.4
135	**0**	**CG**	2.6	13.8	26.5	68.3	0.72	0.71	0.45	56.4
		CG-CP	2.5	12.6	25.7	68.9	0.73	0.72	0.46	49.6
		CP	2.1	14.2	22.4	71.5	0.77	0.74	0.49	47.4
		F	1.9	13.4	24.4	69.9	0.74	0.73	0.46	40.0
	34	**CG**	2.4	14.9	24.5	69.9	0.74	0.73	0.47	55.9
		CG-CP	1.7	13.4	25.4	69.2	0.73	0.72	0.46	37.3
		CP	2.2	13.7	25.7	68.9	0.73	0.72	0.45	48.2
		F	2.0	13.1	25.8	68.8	0.72	0.71	0.45	41.4
Split	**0**	**CG**	1.4	12.5	25.9	68.7	0.72	0.71	0.45	28.6
		CG-CP	1.4	10.7	26.6	68.2	0.72	0.71	0.44	24.5
		CP	1.4	12.1	27.2	67.7	0.71	0.70	0.44	27.9
		F	1.4	12.3	24.6	69.7	0.74	0.72	0.46	27.9
	34	**CG**	1.4	12.2	26.6	68.2	0.72	0.71	0.45	27.6
		CG-CP	1.3	11.2	28.6	66.6	0.69	0.69	0.42	22.6
		CP	1.3	12.6	23.5	70.6	0.75	0.73	0.48	28.4
		F	1.3	11.5	24.9	69.5	0.74	0.72	0.46	24.1
		Wheat N	<0.0001	<0.0001	0.0054	0.0057	0.0094	0.0045	0.0049	<0.0001
		Summer N	--	--	--	--	--	--	--	--
		Summer Crop	--	--	--	--	--	--	--	--
		WN x SN	--	--	--	--	--	--	--	--
		WN x SC	--	--	--	--	--	--	--	--
		SN x SC	--	--	--	--	--	--	--	--
		WN x SN x SC	--	--	--	--	--	--	--	--

Table 26. Winter wheat forage harvest yield and quality results from LCB 2018-2019 second harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NEM), lactation (NEL), and gain (NEG). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N (kg ha^{-1})	Summer N (kg ha^{-1})	Summer Crop	Dry Matter (Mg ha^{-1})	CP (%)	ADF (%)	TDN (%)	NEM (%)	NEL (%)	NEG (%)	N Uptake (kg ha^{-1})
67	0	CG	8.2	5.3	37.0	60.1	0.60	0.62	0.34	69.0
		CG-CP	6.9	5.5	36.4	60.6	0.60	0.62	0.34	61.4
		CP	6.9	5.6	36.6	60.4	0.60	0.62	0.34	61.7
		F	7.8	5.5	37.7	59.6	0.59	0.61	0.33	67.8
	34	CG	7.9	5.4	37.0	60.1	0.60	0.62	0.33	68.0
		CG-CP	7.5	5.5	35.3	61.4	0.62	0.63	0.35	66.3
		CP	7.7	5.6	35.7	61.1	0.61	0.63	0.35	68.4
		F	8.9	5.5	38.0	59.4	0.59	0.61	0.33	79.7
135	0	CG	9.9	5.5	35.4	61.4	0.62	0.63	0.35	86.7
		CG-CP	8.9	5.4	36.1	60.8	0.61	0.63	0.35	76.1
		CP	11.6	5.5	37.0	60.1	0.60	0.61	0.33	108.2
		F	9.3	5.3	36.1	60.8	0.61	0.62	0.35	79.4
	34	CG	9.6	5.1	36.1	60.8	0.61	0.62	0.35	77.4
		CG-CP	8.8	5.4	37.4	59.8	0.59	0.61	0.33	76.3
		CP	10.3	5.7	36.2	60.7	0.61	0.62	0.35	96.9
		F	8.9	5.2	35.2	61.6	0.62	0.63	0.36	74.4
Split	0	CG	14.3	6.1	36.7	60.3	0.60	0.62	0.34	138.5
		CG-CP	13.7	6.7	37.1	60	0.60	0.62	0.34	146.0
		CP	13.5	6.2	36.9	60.2	0.60	0.62	0.34	134.1
		F	13	6.5	36.2	60.7	0.61	0.62	0.35	135.2
	34	CG	13.6	7.3	37.0	60	0.60	0.62	0.34	158.7
		CG-CP	13.5	6.7	37.6	59.6	0.59	0.61	0.33	144.9
		CP	13.2	6.8	36.7	60.3	0.60	0.62	0.34	143.6
		F	12.4	6.6	36.7	60.4	0.60	0.62	0.34	132.0
		Wheat N	<0.0001	<0.0001	0.0749	0.0658	0.0733	0.1286	0.0871	<0.0001
		Summer N	--	--	--	--	--	--	--	--
		Summer Crop	--	--	--	--	--	--	--	--
		WN x SN	--	--	--	--	--	--	--	--
		WN x SC	--	--	--	--	--	--	--	--
		SN x SC	--	--	--	--	--	--	--	--
		WN x SN x SC	--	--	--	--	--	--	--	--

Table 27. Winter wheat forage harvest yield and quality results from LCB 2019 summer harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NEM), lactation (NEL), and gain (NEG). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N	**Summer N**	**Summer Crop**	**Dry Matter**	**CP**	**ADF**	**TDN**	**NE_M**	**NE_L**	**NE_G**	**N Uptake**
(kg ha^{-1})	*(kg ha^{-1})*		*(Mg ha^{-1})*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*	*(%)*	*(kg ha^{-1})*
67	**0**	**CG**	1.0	7.2	43.5	55.0	0.52	0.56	0.27	11.7
		CG-CP	2.4	13.2	41.8	56.4	0.54	0.58	0.29	51.9
		CP	2.7	13.9	41.0	56.9	0.55	0.58	0.29	60.0
		F								
	34	**CG**	1.9	6.1	43.6	55.0	0.52	0.56	0.26	19.3
		CG-CP	3.0	10.3	40.8	57.1	0.55	0.58	0.29	49.3
		CP	3.0	13.6	39.6	58.1	0.57	0.59	0.31	65.1
		F								
135	**0**	**CG**	0.9	7.1	43.8	54.8	0.52	0.56	0.26	10.5
		CG-CP	2.2	11.8	42.5	55.8	0.53	0.57	0.28	42.9
		CP	2.5	12.2	40.7	57.2	0.55	0.58	0.30	53.1
		F								
	34	**CG**	2.0	6.9	44.5	54.2	0.51	0.55	0.25	22.6
		CG-CP	3.0	10.0	41.8	56.3	0.54	0.57	0.29	49.5
		CP	3.3	10.2	43.0	55.5	0.52	0.57	0.27	49.9
		F								
Split	**0**	**CG**	1.0	8.8	45.2	53.7	0.50	0.54	0.25	13.0
		CG-CP	2.5	13.6	40.9	57.0	0.55	0.58	0.29	54.3
		CP	2.2	13.1	41.9	56.3	0.54	0.57	0.29	62.6
		F								
	34	**CG**	2.0	5.7	44.6	54.2	0.51	0.55	0.25	18.1
		CG-CP	2.8	9.3	42.1	56.1	0.54	0.57	0.28	43.8
		CP	3.2	11.5	41.3	56.8	0.55	0.58	0.29	57.4
		F								
		Wheat N	0.9711	0.3515	0.3659	0.3662	0.3421	0.3652	0.4116	0.6676
		Summer Crop	<0.0001	<0.0001	0.2039	0.2114	0.231	0.2447	0.1883	<0.0001
		Summer N	0.001	0.0016	0.9725	0.9912	1	0.9222	0.9687	0.5986
		WN x SC	0.9727	0.5655	0.9325	0.9378	0.9284	0.9427	0.949	0.9139
		WN x SN	0.7881	0.424	0.6362	0.6377	0.6362	0.6973	0.6577	0.8035
		SN x SC	0.6206	0.4066	0.9899	0.9876	0.924	0.9976	0.9938	0.6057
		WN x SC x SN	0.9873	0.8444	0.7079	0.7174	0.7186	0.7306	0.7075	0.9253

Table 28. Winter wheat forage harvest yield and quality results from LCB 2019-2020 first harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NEM), lactation (NEL), and gain (NEG). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**Dry Matter** *(Mg ha^{-1})*	**CP** *(%)*	**ADF** *(%)*	**TDN** *(%)*	**NE_M** *(%)*	**NE_L** *(%)*	**NE_G** *(%)*	**N Uptake** *(kg ha^{-1})*
67	**0**	**CG**	1.6	13.4	25.4	69.1	0.73	0.72	0.46	35.1
		CG-CP	1.8	13.5	23.9	70.3	0.75	0.73	0.47	38.9
		CP	1.7	14.0	23.1	71.0	0.75	0.74	0.48	38.7
		F	1.8	13.9	21.8	72.0	0.77	0.75	0.49	40.7
	34	**CG**	1.9	12.4	27.4	67.6	0.71	0.70	0.44	36.9
		CG-CP	1.9	13.1	25.9	68.7	0.73	0.72	0.45	38.5
		CP	1.5	13.8	24.6	69.7	0.74	0.73	0.47	32.4
		F	2.1	14.4	21.5	72.2	0.78	0.75	0.50	48.6
135	**0**	**CG**	3.0	15.0	21.3	72.3	0.77	0.75	0.50	71.8
		CG-CP	3.1	15.1	21.4	72.3	0.77	0.75	0.49	74.6
		CP	2.2	15.4	20.5	73.0	0.78	0.76	0.50	53.8
		F	4.3	16.2	21.4	72.3	0.78	0.75	0.50	108.0
	34	**CG**	2.9	15.0	21.5	72.2	0.78	0.75	0.50	68.8
		CG-CP	2.7	13.6	22.8	71.2	0.76	0.74	0.48	58.5
		CP	2.1	14.6	21.4	72.2	0.77	0.75	0.49	50.1
		F	3.0	15.4	22.3	71.5	0.76	0.74	0.49	99.6
Split	**0**	**CG**	1.5	14.1	22.1	71.7	0.77	0.75	0.49	33.1
		CG-CP	1.3	13.5	23.9	70.3	0.75	0.73	0.47	27.5
		CP	1.6	13.4	21.7	72.1	0.77	0.75	0.49	33.4
		F	1.5	14.2	22.4	71.5	0.77	0.74	0.49	35.0
	34	**CG**	1.6	11.7	27.4	67.6	0.71	0.70	0.44	28.9
		CG-CP	1.8	13.0	24.2	70.0	0.75	0.73	0.47	37.6
		CP	1.3	13.7	22.5	71.4	0.76	0.74	0.49	28.3
		F	2.9	14.3	21.7	72.0	0.77	0.75	0.49	66.4
		Wheat N	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0001	0.0002	<0.0001
		Summer Crop	0.0004	0.0003	0.0012	0.0012	0.0013	0.0012	0.0015	<.0001
		Summer N	0.682	0.0026	0.0097	0.0088	0.0142	0.0125	0.0125	0.8375
		WN x SC	0.0844	0.4732	0.0834	0.0756	0.0749	0.0868	0.0708	0.0173
		WN x SN	0.1928	0.7693	1	1	0.9604	0.9758	0.8976	0.1294
		SN x SC	0.6448	0.2875	0.3164	0.3308	0.4406	0.3359	0.3048	0.615
		WN x SC x SN	0.7011	0.1368	0.3594	0.3674	0.2898	0.5062	0.3638	0.6023

Table 29. Winter wheat forage harvest yield and quality results from LCB 2019-2020 second harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NEM), lactation (NEL), and gain (NEG). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**Dry Matter** *(Mg ha^{-1})*	**CP** *(%)*	**ADF** *(%)*	**TDN** *(%)*	**NE$_M$** *(%)*	**NE$_L$** *(%)*	**NE$_G$** *(%)*	**N Uptake** *(kg ha^{-1})*
67	**0**	**CG**	3.4	8.7	30.1	65.5	0.68	0.68	0.41	46.8
		CG-CP	3.8	9.1	30.2	65.4	0.68	0.68	0.41	55.1
		CP	3.8	9.4	30.0	65.5	0.68	0.68	0.41	57.6
		F	4.7	9.2	31.5	64.4	0.66	0.66	0.40	69.1
	34	**CG**	3.1	9.1	30.1	65.5	0.68	0.68	0.41	44.7
		CG-CP	3.1	9.7	28.2	67.0	0.70	0.70	0.43	47.0
		CP	3.6	9.5	32.7	63.4	0.65	0.65	0.38	55.3
		F	4.2	8.8	32.4	63.7	0.65	0.66	0.39	60.0
135	**0**	**CG**	4.6	9.3	30.6	65.1	0.67	0.67	0.41	67.7
		CG-CP	5.6	9.3	29.8	65.7	0.68	0.68	0.41	83.3
		CP	5.7	10.1	29.4	66.0	0.69	0.68	0.42	92.6
		F	6.3	11.5	31.2	64.6	0.67	0.67	0.40	114.8
	34	**CG**	5.4	9.3	29.5	66.0	0.68	0.68	0.41	80.5
		CG-CP	4.6	9.4	30.1	65.5	0.68	0.68	0.41	68.6
		CP	4.5	10.2	30.1	65.5	0.68	0.68	0.41	74.2
		F	5.1	9.8	29.6	65.8	0.68	0.68	0.41	80.0
Split	**0**	**CG**	6.2	10.5	30.3	65.3	0.68	0.67	0.41	103.7
		CG-CP	6.5	10.7	30.9	64.8	0.67	0.67	0.40	110.4
		CP	6.9	10.6	32.6	63.6	0.65	0.65	0.38	116.5
		F	6.5	10.4	32.1	63.9	0.66	0.66	0.39	107.1
	34	**CG**	5.6	10.8	29.1	66.2	0.69	0.68	0.42	96.4
		CG-CP	6.1	10.8	29.7	65.8	0.68	0.68	0.41	105.4
		CP	6.5	11.4	30.0	65.6	0.68	0.68	0.41	119.4
		F	7.0	11.0	31.0	64.7	0.67	0.67	0.40	123.2
		Wheat N	<0.0001	<0.0001	0.4200	0.4211	0.3402	0.4706	0.4670	<0.0001
		Summer Crop	0.0002	0.0523	0.0697	0.0676	0.0553	0.0591	0.0839	<0.0001
		Summer N	0.0040	0.5042	0.2532	0.2551	0.2820	0.1957	0.3031	0.0339
		WN x SC	0.6923	0.1105	0.6744	0.6732	0.5763	0.5829	0.6977	0.6682
		WN x SN	0.5312	0.1014	0.2250	0.2209	0.2919	0.1802	0.1375	0.0707
		SN x SC	0.3036	0.2275	0.7952	0.7928	0.7524	0.7357	0.8225	0.4829
		WN x SC x SN	0.0971	0.4367	0.4996	0.4978	0.5105	0.4125	0.6859	0.0278

Table 30. Winter wheat forage harvest yield and quality results from LCB 2020 summer harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NEM), lactation (NEL), and gain (NEG). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**Dry Matter** *(Mg ha^{-1})*	**CP** *(%)*	**ADF** *(%)*	**TDN** *(%)*	**NE$_M$** *(%)*	**NE$_L$** *(%)*	**NE$_G$** *(%)*	**N Uptake** *(kg ha^{-1})*
67	**0**	**CG**	0.6	8.9	40.8	57.1	0.55	0.58	0.30	9.1
		CG-CP	3.8	13.7	36.2	60.7	0.61	0.62	0.35	82.4
		CP	2.4	12.3	36.6	60.4	0.60	0.62	0.34	49.1
		F								
	34	**CG**	3.8	8.1	40.9	57.1	0.55	0.59	0.30	49.6
		CG-CP	5.5	9.6	40.1	57.7	0.56	0.59	0.30	84.8
		CP	4.4	11.0	38.6	58.9	0.58	0.60	0.32	78.2
		F								
135	**0**	**CG**	1.1	8.1	41.5	56.6	0.54	0.58	0.29	14.1
		CG-CP	4.2	13.1	34.8	61.8	0.62	0.64	0.36	88.0
		CP	2.6	13.3	33.9	62.5	0.63	0.64	0.37	57.4
		F								
	34	**CG**	4.4	8.6	41.6	56.5	0.54	0.58	0.29	60.8
		CG-CP	6.3	12.3	38.0	59.3	0.58	0.61	0.33	121.3
		CP	4.5	11.0	39.4	58.2	0.57	0.60	0.31	82.7
		F								
Split	**0**	**CG**	1.5	9.1	40.3	57.6	0.56	0.59	0.30	22.3
		CG-CP	2.6	12.0	37.6	59.6	0.59	0.61	0.33	49.5
		CP	5.2	12.7	35.1	61.6	0.62	0.63	0.36	98.6
		F								
	34	**CG**	3.3	10.0	39.3	58.3	0.57	0.60	0.32	52.5
		CG-CP	4.5	9.2	40.7	57.2	0.55	0.59	0.30	67.1
		CP	4.8	10.1	39.6	58.1	0.57	0.59	0.31	78.1
		F								
		Wheat N	0.487	0.6374	0.661	0.6541	0.6653	0.609	0.7057	0.2696
		Summer Crop	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	0.0001	<0.0001
		Summer N	<0.0001	0.0053	0.0003	0.0003	0.0002	0.0006	0.0003	0.0006
		WN x SC	0.0115	0.3359	0.2049	0.1971	0.197	0.1991	0.2043	0.0134
		WN x SN	0.1609	0.6373	0.806	0.8056	0.7882	0.7744	0.7918	0.2415
		SN x SC	0.0998	0.0717	0.012	0.0121	0.0077	0.0129	0.009	0.1713
		WN x SC x SN	0.6613	0.6521	0.756	0.7594	0.7848	0.8892	0.7347	0.5295

Table 31. Winter wheat forage harvest yield and quality results from LCB 2020-2021 harvest. Dry matter biomass yield, crude protein (CP), acid detergent fiber (ADF), total digestible nutrients (TDN), net energy for maintenance (NEM), lactation (NEL), and gain (NEG). P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**Dry Matter** *(Mg ha^{-1})*	**CP** *(%)*	**ADF** *(%)*	**TDN** *(%)*	**NE$_M$** *(%)*	**NE$_L$** *(%)*	**NE$_G$** *(%)*	**N Uptake** *(kg ha^{-1})*
67	0	**CG**	2.6	8.9	31.1	64.6	0.67	0.67	0.40	37.6
		CG-CP	3.6	9.0	36.5	60.5	0.60	0.62	0.34	51.8
		CP	3.5	8.6	30.1	65.5	0.68	0.68	0.41	47.1
		F	3.8	8.6	30.6	65.1	0.67	0.67	0.41	51.0
	34	**CG**	3.0	8.6	32.3	63.7	0.65	0.66	0.39	54.5
		CG-CP	3.4	9.0	29.7	65.8	0.68	0.68	0.42	48.6
		CP	3.9	8.5	33.3	63.0	0.64	0.65	0.38	53.0
		F	4.0	10.1	30.4	65.2	0.67	0.67	0.41	63.8
135	0	**CG**	4.8	8.9	29.6	65.8	0.68	0.68	0.41	67.3
		CG-CP	4.7	9.0	33.6	62.8	0.64	0.65	0.37	67.7
		CP	5.5	9.5	32.3	63.8	0.65	0.66	0.39	82.3
		F	5.3	8.5	31.4	64.5	0.66	0.66	0.40	71.6
	34	**CG**	5.5	9.1	27.8	67.3	0.71	0.70	0.43	79.6
		CG-CP	5.0	8.7	29.5	65.9	0.68	0.68	0.42	70.3
		CP	5.7	8.7	30.0	65.5	0.68	0.68	0.41	78.9
		F	5.4	9.0	31.1	64.8	0.67	0.67	0.40	78.1
Split	0	**CG**	4.8	11.0	30.3	65.4	0.67	0.68	0.41	85.3
		CG-CP	4.7	11.8	31.9	64.0	0.66	0.66	0.39	90.5
		CP	5.4	10.7	30.6	65.1	0.67	0.67	0.41	93.1
		F	5.3	11.1	30.9	64.8	0.67	0.67	0.40	94.3
	34	**CG**	5.0	11.8	33.9	62.5	0.63	0.64	0.37	94.6
		CG-CP	5.7	12.2	31.8	64.2	0.66	0.66	0.39	111.3
		CP	5.2	11.5	29.5	65.9	0.68	0.68	0.41	95.9
		F	6.6	10.4	32.4	63.7	0.65	0.66	0.39	110.7
		Wheat N	<0.0001	<0.0001	0.2797	0.2700	0.2244	0.2857	0.244	<0.0001
		Summer Crop	0.0924	0.5967	0.3053	0.3090	0.2884	0.3842	0.3577	0.5437
		Summer N	0.0131	0.3319	0.2718	0.2685	0.1971	0.2707	0.2845	0.0227
		WN x SC	0.7238	0.3488	0.2356	0.2337	0.2254	0.2073	0.2312	0.7328
		WN x SN	1	0.6716	0.0809	0.0841	0.0610	0.0518	0.0757	0.9313
		SN x SC	0.6389	0.8649	0.0208	0.0211	0.0180	0.0161	0.0198	0.6569
		WN x SC x SN	0.5240	0.3645	0.1433	0.1438	0.1359	0.1414	0.1581	0.9643

Table 32. Cumulative winter wheat forage harvest yield in Mg ha-1 from each year and system total at LCB. P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N	**Summer N**	**Summer Crop**	**2018 – 2019**	**2019 – 2020**	**2020 – 2021**	**Total**
(kg ha^{-1})	*(kg ha^{-1})*		*(Mg ha^{-1})*	*(Mg ha^{-1})*	*(Mg ha^{-1})*	*(Mg ha^{-1})*
67	**0**	**CG**	9.6	5.0	2.6	17.3
		CG-CP	8.3	5.6	3.6	17.5
		CP	8.1	5.6	3.5	17.1
		F	9.1	6.5	3.8	19.4
	34	**CG**	9.4	5.0	3.0	17.4
		CG-CP	8.7	4.9	3.4	17.1
		CP	9.4	5.1	3.9	18.4
		F	10.4	6.3	4.0	20.7
135	**0**	**CG**	12.0	7.5	4.8	24.3
		CG-CP	10.8	8.7	4.7	24.2
		CP	14.1	7.9	5.5	27.5
		F	11.8	10.5	5.3	27.5
	34	**CG**	11.8	8.3	5.5	25.6
		CG-CP	10.8	7.3	5.0	23.1
		CP	12.6	6.7	5.7	25.0
		F	10.6	8.1	5.4	24.2
Split	**0**	**CG**	15.8	7.7	4.8	28.3
		CG-CP	15.0	7.8	4.7	27.5
		CP	14.9	8.5	5.4	28.8
		F	14.4	8.1	5.3	27.8
	34	**CG**	14.9	7.2	5.0	27.1
		CG-CP	14.8	7.9	5.7	28.4
		CP	14.6	7.8	5.2	27.7
		F	13.7	9.9	6.6	30.1
		Wheat N	<0.0001	<0.0001	<0.0001	<0.0001
		Summer Crop	--	<0.0001	0.0924	0.0741
		Summer N	--	0.0728	0.0131	0.6952
		WN x SC	--	0.6749	0.7238	0.7941
		WN x SN	--	0.0744	1.0000	0.3223
		SN x SC	--	0.5202	0.6389	0.931
		WN x SC x SN	--	0.0637	0.5240	0.4847

Table 33. Cumulative winter wheat forage N uptake in kg ha-1 from each year and system total at LCB. P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**2018 – 2019** *(kg ha^{-1})*	**2019 – 2020** *(kg ha^{-1})*	**2020 – 2021** *(kg ha^{-1})*	**Total** *(kg ha^{-1})*
67	**0**	**CG**	96.8	82.0	37.6	216.4
		CG-CP	85.2	94.0	51.8	231.1
		CP	82.4	96.3	47.1	225.7
		F	90.6	109.7	51.0	251.4
	34	**CG**	94.2	81.7	54.5	216.7
		CG-CP	88.7	85.5	48.6	222.9
		CP	95.3	87.8	53.0	236.0
		F	104.8	108.6	63.8	277.2
135	**0**	**CG**	134.0	139.5	67.3	340.9
		CG-CP	116.1	157.9	67.7	341.7
		CP	164.6	146.4	82.3	393.3
		F	128.9	222.8	71.6	423.3
	34	**CG**	125.6	149.3	79.6	354.5
		CG-CP	117.7	127.1	70.3	315.0
		CP	152.8	124.3	78.9	355.9
		F	111.7	154.7	78.1	344.5
Split	**0**	**CG**	166.4	136.8	85.3	388.5
		CG-CP	173.9	137.9	90.5	402.3
		CP	162.6	150.0	93.1	405.6
		F	159.7	142.1	94.3	396.0
	34	**CG**	187.0	125.3	94.6	407.0
		CG-CP	169.1	143.0	111.3	423.4
		CP	171.2	147.7	95.9	414.9
		F	154.6	189.6	110.7	454.9
		Wheat N	<0.0001	<0.0001	<0.0001	<0.0001
		Summer Crop	--	<0.0001	0.5437	0.0334
		Summer N	--	0.1326	0.0227	0.9547
		WN x SC	--	0.3583	0.7328	0.7875
		WN x SN	--	0.0109	0.9313	0.0502
		SN x SC	--	0.8621	0.6569	0.9291
		WN x SC x SN	--	0.0175	0.9643	0.5418

Table 34. Cumulative forage harvest yield in Mg ha-1 from each year that included a summer and two and three year totals at LCB. P-values represent the significance of each variable and all interactions Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**2018 – 2019** *(Mg ha^{-1})*	**2019 – 2020** *(Mg ha^{-1})*	**2018 – 2020** *(Mg ha^{-1})*	**2018 – 2021** *(Mg ha^{-1})*
67	**0**	**CG**	10.6	5.6	16.3	18.9
		CG-CP	10.7	9.4	20.1	23.8
		CP	10.8	7.9	18.8	22.2
		F	9.1	6.5	15.6	19.4
	34	**CG**	11.4	8.7	20.1	23.1
		CG-CP	11.8	10.4	22.2	25.6
		CP	12.3	9.5	21.8	25.7
		F	10.4	6.3	16.8	20.7
135	**0**	**CG**	12.9	8.7	21.6	26.3
		CG-CP	13.0	13.0	25.9	30.6
		CP	16.6	10.5	27.2	32.6
		F	11.8	10.5	22.3	27.5
	34	**CG**	13.8	12.7	26.6	32.0
		CG-CP	13.8	13.6	27.4	32.4
		CP	15.9	11.1	27.0	32.7
		F	10.6	8.1	18.8	24.2
Split	**0**	**CG**	16.8	9.2	25.9	30.8
		CG-CP	17.5	10.4	27.9	32.6
		CP	17.1	13.7	30.8	36.3
		F	14.4	8.1	22.5	27.8
	34	**CG**	16.9	10.5	27.4	32.4
		CG-CP	17.6	12.4	30.0	35.6
		CP	17.8	12.7	30.5	35.7
		F	13.7	9.9	23.5	30.1
		Wheat N	<0.0001	<0.0001	<0.0001	<0.0001
		Summer Crop	<0.0001	<0.0001	<0.0001	<0.0001
		Summer N	0.4548	0.0017	0.0275	0.0083
		WN x SC	0.4791	0.0158	0.8096	0.8186
		WN x SN	0.5653	0.724	0.4637	0.5823
		SN x SC	0.9312	0.0067	0.1763	0.2163
		WN x SC x SN	0.9796	0.053	0.6442	0.4264

Table 35. Cumulative N uptake in kg ha-1 from each year that included a summer and two and three year totals at LCB. P-values represent the significance of each variable and all interactions. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**2018 – 2019** *(kg ha^{-1})*	**2019 – 2020** *(kg ha^{-1})*	**2018 – 2020** *(kg ha^{-1})*	**2018 – 2021** *(kg ha^{-1})*
67	**0**	**CG**	108.5	91.1	199.6	237.2
		CG-CP	137.2	176.5	313.6	365.4
		CP	142.4	145.4	287.8	334.8
		F	90.6	109.7	200.3	251.4
	34	**CG**	113.5	131.2	244.7	285.6
		CG-CP	138.1	170.3	308.4	357.0
		CP	160.4	166.0	326.3	379.3
		F	104.8	108.6	213.5	277.2
135	**0**	**CG**	144.5	153.6	298.1	365.5
		CG-CP	159.0	245.9	405.0	472.7
		CP	217.6	203.9	421.5	503.8
		F	128.9	222.8	351.7	423.3
	34	**CG**	148.2	210.0	358.3	437.9
		CG-CP	167.1	248.4	415.5	485.8
		CP	202.7	206.9	409.6	488.5
		F	111.7	154.7	266.4	344.5
Split	**0**	**CG**	179.4	159.1	338.5	423.8
		CG-CP	228.2	187.5	415.6	506.1
		CP	209.5	248.6	458.1	551.2
		F	159.7	142.1	301.8	396.0
	34	**CG**	205.1	177.8	382.9	477.5
		CG-CP	212.9	210.2	423.1	534.4
		CP	228.7	225.8	454.5	550.4
		F	154.6	189.6	344.2	454.9
		Wheat N	<0.0001	<0.0001	<0.0001	<0.0001
		Summer Crop	<0.0001	<0.0001	<0.0001	<0.0001
		Summer N	0.6037	0.1746	0.1965	0.0715
		WN x SC	0.4288	0.0613	0.9137	0.9626
		WN x SN	0.6538	0.5243	0.3844	0.3514
		SN x SC	0.8456	0.1052	0.1801	0.2636
		WN x SC x SN	0.864	0.0386	0.3275	0.335

Table 36. Overall fertilizer use efficiency (FUE) from each year that included a summer and two and three year totals at LCB. P-values represent the significance of each variable and all interactions. FUE values less than 100% shows less N was taken up than applied by fertilizer. Wheat N treatments are 67 kg N ha-1 at pre-plant, 135 kg ha-1 at pre-plant, and a split application of 67 kg N ha-1 pre-plant and 67 kg N ha-1 at top-dress. Summer N treatments are 0 or 34 kg N ha-1, Summer crop treatments crabgrass (CG), cowpea (CP), crabgrass-cowpea mixture (CG-CP), and fallow (F)

Wheat N *(kg ha^{-1})*	**Summer N** *(kg ha^{-1})*	**Summer Crop**	**2018 – 2019** *(%)*	**2019 – 2020** *(%)*	**2018 – 2020** *(%)*	**2018 – 2021** *(%)*
67	**0**	**CG**	161	135	148	118
		CG-CP	204	262	233	181
		CP	212	216	214	166
		F	135	163	149	125
	34	**CG**	113	130	121	121
		CG-CP	137	169	153	152
		CP	165	169	164	163
		F	104	108	106	118
135	**0**	**CG**	107	114	111	91
		CG-CP	112	177	147	115
		CP	162	152	157	125
		F	96	166	131	105
	34	**CG**	88	125	107	100
		CG-CP	105	156	127	113
		CP	121	123	122	112
		F	66	92	79	79
Split	**0**	**CG**	133	118	126	105
		CG-CP	159	131	149	122
		CP	156	185	170	137
		F	119	106	112	98
	34	**CG**	122	106	114	109
		CG-CP	127	125	126	122
		CP	136	134	135	126
		F	92	113	102	104
		Wheat N	<0.0001	<0.0001	<0.0001	<0.0001
		Summer Crop	<0.0001	<0.0001	<0.0001	<0.0001
		Summer N	<0.0001	<0.0001	<0.0001	0.0907
		WN x SC	0.4911	0.0057	0.0533	0.0819
		WN x SN	0.1109	0.0654	0.0105	0.5016
		SN x SC	0.9092	0.0622	0.0805	0.258
		WN x SC x SN	0.72	0.0444	0.2124	0.3015

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APPENDICES

Average Daily Gain

Cattle productivity of the study was also evaluated based on average daily gain (ADG) of cattle that allowed to graze the paddocks. Response of ADG to treatment were only found in the first two years of the study, treatment means for the all years can be found in Table 5. In 2015-2016 tillage influenced ADG in both the summer forage and wheat seasons. The use of tillage decreased average daily gain by 0.3 kg d^{-1} during both grazing seasons in the first year (App. Table 3). Year two of the study (2016-2017) the ADG of the cattle on wheat was influenced by the interaction of tillage and summer cropping method. The use of NTSC decreased the ADG to 1.2 kg d^{-1} in comparison to the average of 1.4 kg d^{-1} in all other treatments. 2017 summer had a similar decrease due to the use of no-till, where the ADG was decreased from 0.9 kg d^{-1}, to 0.7 kg d^{-1}. Fourth and final grazing year (2019-2020) resulted in a 0.1 kg d^{-1} decrease in cattle when grazing the wheat which followed a summer forage (1.2 kg d^{-1}), however unlike previous year no tillage influence was observed.

Appendix Table 1. P-Value for each dependent variable from the standard and Haney soil test analysis.

Variable	Tillage	Crop	Date	Tillage x Crop	Tillage x Date	Crop x Date	Tillage x Crop x Date
K_H	0.4754	0.9833	>.0001	0.3099	0.3433	0.9484	0.2201
Ca	0.2956	0.0593	0.0052	0.0203	0.9955	0.9718	0.8102
Ca_{sat}	0.9238	0.0644	>.0001	0.0674	0.9118	0.9694	0.2589
CEC	0.1267	0.0066	>.0001	0.0281	0.9966	0.9018	0.9252
OM_H	>.0001	0.0018	0.0008	0.0221	0.0916	0.9871	0.8692
pH_H	0.7382	0.0445	>.0001	0.1876	0.5362	0.6852	0.6625
SS_H	0.0123	0.8312	0.0029	0.1781	0.3701	0.3628	0.368
B pH_H	0.2296	0.0403	>.0001	0.145	0.7878	0.9441	0.495
H2O_N_O	0.002	0.5096	>.0001	0.7753	0.018	0.0246	0.4363
H2O_N_T	0.9729	>.0001	>.0001	0.1348	>.0001	>.0001	0.0718
H2O_C	0.0002	0.0116	>.0001	0.0633	0.5824	0.0363	0.4351
H3A_NH_4^+	0.0882	0.0835	>.0001	0.7965	0.0255	0.6223	0.9894
H3A_Al	0.1511	0.2005	>.0001	0.531	0.8276	0.7259	0.6495
H3A _Ca	0.3671	0.3352	>.0001	0.0044	0.999	0.9996	0.7421
H3A_Fe	0.0541	0.6252	>.0001	0.8754	0.1594	0.9	0.787
H3A_K	0.5368	0.98	>.0001	0.4183	0.9933	0.6361	0.8853
H3A_N_I	0.0553	>.0001	>.0001	0.0809	>.0001	>.0001	0.4738
H3A_P_I	0.6263	0.7594	>.0001	0.1014	0.493	0.9712	0.5873
H3A_NO_3	0.1034	>.0001	>.0001	0.0567	>.0001	>.0001	0.3655
H3A_P_O	0.3405	0.5878	>.0001	0.1815	0.1811	0.9737	0.1336
H3A_P_T	0.466	0.9593	>.0001	0.2926	0.2839	0.9255	0.4321
N_H	0.8245	>.0001	>.0001	0.1125	>.0001	0.001	0.056
H_{sat}	0.8994	0.4328	0.3482	0.2422	0.4069	0.6127	--
K_{STD}	0.8892	0.3767	>.0001	0.4446	0.9992	0.4019	0.8204
K_{sat}	0.0007	0.2483	0.2833	0.5448	0.9993	0.9572	0.8456
N_{Diff}	0.2758	0.218	>.0001	0.6079	0.2005	0.8629	0.0234
Total N_{STD}	0.0019	>.0001	>.0001	0.9427	>.0001	>.0001	0.0806
M3P	0.714	0.0272	>.0001	0.1393	0.7794	0.901	0.3416
Mg	0.6845	0.0013	0.2547	0.0997	0.9987	0.8292	0.9964
Mg Sat	0.0194	0.0047	>.0001	0.6693	0.9915	0.9585	0.9963
N_{I-STD}	0.0003	>.0001	>.0001	0.8186	>.0001	>.0001	0.0631
N_{min}	0.1254	0.467	>.0001	0.3658	0.8173	0.6179	0.0198
N_{save}	0.2769	0.2175	>.0001	0.6119	0.2012	0.8613	0.0237
Na	0.0048	0.0343	0.1693	0.0005	0.8566	0.9471	0.4397
Na_{sat}	0.0282	0.058	0.1876	0.0027	0.8755	0.9607	0.3236
Nutrient Value	0.4662	0.0528	>.0001	0.2761	0.6833	0.217	0.7063
OM_{STD}	>.0001	0.0008	>.0001	0.6247	0.0883	0.9302	0.916
C:N Ratio	0.4667	0.0089	>.0001	0.2854	0.0621	0.5199	0.5893

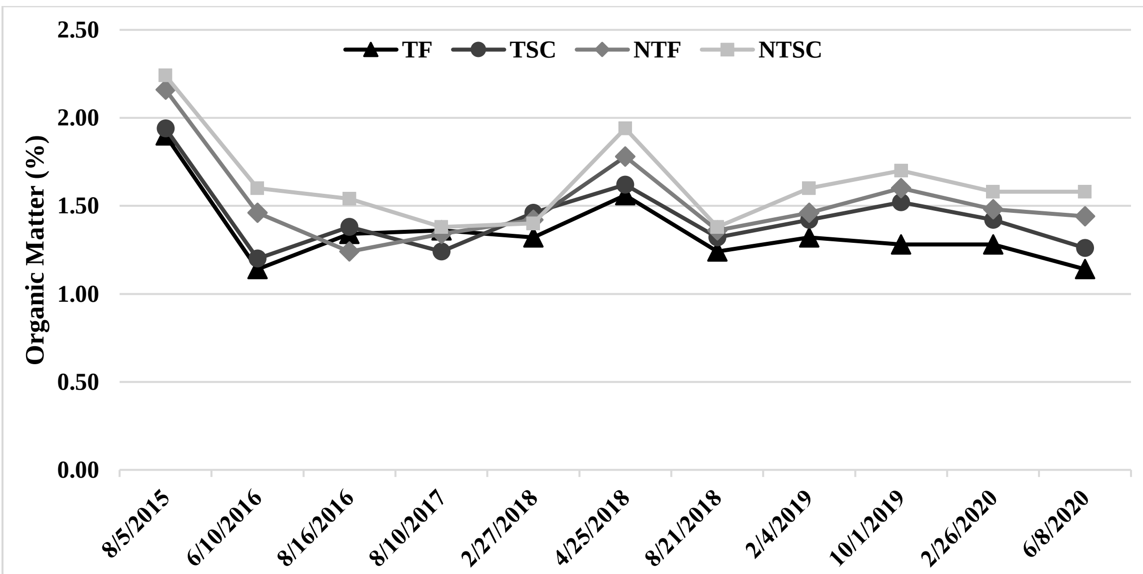
N $_{\textbf{Release}}$	0.1641	0.3891	>.0001	0.476	0.3081	0.9716	0.0201
N $_{\textbf{Reserve}}$	0.6459	0.2845	>.0001	0.4078	0.0835	0.7926	0.5049
P $_{\textbf{Reserve}}$	0.8188	0.7217	>.0001	0.7191	0.389	0.7223	0.2548
P $_{\textbf{Min}}$	0.5161	0.7352	>.0001	0.6823	0.4589	0.7939	0.0055
P $_{\textbf{(Al/Fe)}}$	0.4495	0.5419	0.0004	0.0564	0.1361	0.7981	0.1526
P $_{\textbf{(Ca)}}$	0.1294	0.4196	0.422	0.8586	0.5604	0.9887	0.9091
pH $_{\textbf{STD}}$	0.6349	0.0017	0.1062	0.2478	0.9997	0.6013	0.9084
Soil Health	0.0918	0.9723	>.0001	0.2851	0.5878	0.8568	0.021
CO_2_C	0.9791	0.97	>.0001	0.0623	0.696	0.9994	0.0383
SS $_{\textbf{STD}}$	0.2819	0.7825	>.0001	0.0049	0.0652	0.0022	0.1429
B pH $_{\textbf{STD}}$	0.1366	0.5496	>.0001	0.3085	0.9199	0.6366	0.9791
N $_{\textbf{Traditional}}$	0.1451	>.0001	>.0001	0.0654	>.0001	>.0001	0.4488

Appendix Table 2 Soil test variables that responded to date, Initial soil test value, Final soil test value change in value from start of the study to last sample date, % change, and p-value of difference.

Variable	Initial	final	Change	% Change	P-value
OM_H	2.06	1.36	-0.71	34.20	0.022
K_{STD}	221.0	176.8	-44.3	20.00	<0.0001
B pH_{STD}	6.81	7.25		36.30	0.0268
M3P	88.7	66.0	-22.6	25.50	<0.0001
Ca	1936	1778	-158	8.20	0.4025
CEC	8.39	6.35	-2.04	24.30	0.0004
Ca_{sat}	50.5	63.2	12.8	25.30	<0.0001
Mg_{sat}	21.1	31.0	9.9	47.00	<0.0001
pH_H	5.82	5.85		93.30	0.237
B pH_H	6.80	6.65		141.30	0.0016
SS_H	0.26	0.19	-0.07	25.30	0.7768
OM_H	2.13	1.82	-0.31	14.60	0.0215
$H3A\_P_I$	25.7	13.1	-12.6	49.10	<0.0001
$H3A\_P_O$	16.7	7.30	-9.4	56.20	<0.0001
$H3A\_P_T$	42.3	20.3	-22.0	52.00	0.6562
H3A_K	106	51.6	-54.6	51.50	0.0015
H3A_Al	543	224	-320	58.80	<0.0001
H3A_Fe	481	187	-294	61.10	<0.0001
H3A_Ca	674	1116	442	65.60	<0.0001
C:N Ratio	10.1	15.8	5.7	56.80	<0.0001
$P_{Reserve}$	7.85	3.3	-4.6	58.00	<0.0001
$P_{(Al/Fe)}$	4.96	3.5	-1.46	29.40	<0.0001
$N_{Reserve}$	10.8	9.58	-1.18	11.00	0.0482
K_H	81.7	39.2	-42.6	52.10	<0.0001
Nutrient Value	122	66.2	-55.9	45.70	<0.0001

Appendix Table 3. Standard soil test organic matter OM_{STD} from each sampling date overtime of the study. Treatments are no-till summer forage (NTSC), no-till summer fallow (NTF), tilled summer forage (TSC), tilled fallow (TF).

Treatment	8/5/2015	6/10/2016	8/16/2016	8/10/2017	2/27/2018	4/25/2018	8/21/2018	2/4/2019	10/1/2019	2/26/2020	6/8/2020
	-----	-----	-----	-----	-----	%	-----	-----	-----	-----	-----
NTSC	2.24	1.60	1.54	1.38	1.40	1.94	1.38	1.60	1.70	1.58	1.58
NTF	2.16	1.46	1.24	1.34	1.42	1.78	1.36	1.46	1.60	1.48	1.44
TSC	1.94	1.20	1.38	1.24	1.46	1.62	1.32	1.42	1.52	1.42	1.26
TF	1.90	1.14	1.34	1.36	1.32	1.56	1.24	1.32	1.28	1.28	1.14



Appendix Figure 1. Standard soil test organic matter OM_{STD} from each sampling date overtime of the study. Treatments are no-till summer forage (NTSC), no-till summer fallow (NTF), tilled summer forage (TSC), tilled fallow (TF)

Appendix Table 4 Average daily gain (ADG) of cattle grazing paddocks during each season of the study. P-value reported for significant response with-in season. Treatments are no-till summer forage (NTSC), no-till summer fallow (NTF), tilled summer forage (TSC), tilled fallow (TF).

	2015-2016		2016-2017		2018	2018-2019		2019-2020
Treatment	**Winter Wheat**	**Summer Crop**	**Winter Wheat**	**Summer Crop**	**Summer Crop**	**Winter Wheat**	**Summer Crop**	**Winter Wheat**
	--- *kg hd⁻¹ d⁻¹* ---							
NTSC	1.5	1.3	1.2	0.7	1.1	1.15	0.9	1.2
NTF	1.5	--	1.4	--	--	1.13	--	1.3
TSC	1.2	1.0	1.4	0.9	1.1	1.13	--	1.2
TF	1.2	--	1.4	--	--	1.14	--	1.3
Tillage	<0.0001	0.0112	ns	0.0089	ns	ns	ns	ns
Crop	ns	Ns	0.0006	ns	ns	ns	ns	0.0008
Interaction	ns	Ns	0.0253	ns	ns	ns	ns	ns

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