Grain sorghum response to cover crops under a no-till system

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Abstract

Cover crops (CCs) are included in rotations between cash crops for many reasons, including reducing erosion, compaction, and sequestering nutrients for optimal crop performance. The objectives of this study were to i) determine the effects of increasing cropping system intensity on CC biomass accumulation, C:N ratio, and residual inorganic profile nitrogen and ii) determine how intensity effects sorghum (*Sorghum bicolor* L.) growth, development, and yield in a no-till wheat (*Triticum aestivum* L.), sorghum, soybean (*Glycine max* L.) rotation. The experiment was conducted in a randomized complete block design with four treatments: chemical fallow (CF), double-crop soybeans (DSB), double-crop soybeans plus a spring cover crop before sorghum (DSBCC), and a summer cover crop mixture after wheat (CCMIX). Nitrogen (N) rates consisting of 0, 40, 80, 120, and 160 pounds acre^{-1} were subsurface banded after sorghum planting. Sorghum growth and development were characterized by Canopeo (percent canopy cover) and GreenSeeker (NDVI), from seedling through boot stages, by recording days from planting to half bloom, and by chlorphyll readings (SPAD) at half bloom or early grain fill. Sorghum biomass was sampled after physiological maturity to determine N uptake and yield components. Averaged over three years, summer and fall growth of CCMIX produced the greatest biomass at more than 2,000 pounds acre^{-1} and had the greatest C:N ratio compared to DSBCC and CCMIX sampled in the spring. Residual inorganic profile N at sorghum planting, when averaged over years, was roughly 26 pounds acre^{-1} and 13 pounds acre^{-1} less after DSBCC and CCMIX, respectively compared to after CF and DSB. Including a spring cover crop before sorghum (DSBCC) consistently reduced vegetative growth and development of sorghum.Sorghum growth response to CCMIX was inconsistent depending on year. In 2018, when there was no winter survival of the cover crop, sorghum growth after CCMIX was not

different from CF. The CCMIX treatment reduced sorghum SPAD values by 6% and 7% in 2017 and 2019, respectively, and N uptake by 41 and 27 pounds acre^{-1} in 2017 and 2019, respectively. The spring cover crop immediately before sorghum planting (DSBCC) reduced sorghum biomass by 9% (2017) and 27% (2018) compared to CF, though CF was not different from DSB and CCMIX. In 2019, DSBCC was not different from CF, and sorghum after DSB had 10% greater biomass yield than sorghum after DSBCC. Sorghum grain yield was reduced by more than 50% after DSBCC in 2018 compared to CF, though CF, DSB, and CCMIX were not different. In 2019, sorghum grain yields after CF, DSBCC, and CCMIX were not different, and sorghum after DSB had the greatest yields, 7% more than DSBCC. Including double crop or cover crop in a no-till cropping system slowed early-seasoon growth and development and reduced N uptake of the subsequent sorghum crop but had minimal impact on grain yield with adequate weather conditions. However, a spring-planted CC with substantial biomass accumulation immediately before sorghum planting substantially reduced sorghum yield when spring rainfall was below normal.

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Chapter 1 - Literature review

Abstract

It is no question that human population is growing and will soon force large amounts of land out of production to meet demands. As a result, the agricultural community no longer has the luxury of mono-cropping, and other alternatives such as crop rotation must be practiced to increase productivity. Not only is increasing productivity important, but also sustainability of the land is of great importance. If proper stewardship is absent, then further land degradation will occur and result in fewer acres to support the human population. Crop rotation has been practiced since antiquity, and one common practice is growing cover crops between cash crops. Cover crops are short term crops that have been shown to improve soil structure and influence crop productivity. Grain sorghum is an important cereal crop that is grown worldwide and has attributes that allow this crop to be grown in challenging conditions. Previous research has documented positive relationships between cover crops, crop rotations, and the productivity of grain crops. Therefore, our hypothesis was that increasing cropping intensity during fallow period between wheat and sorghum with double crops and cover crops will increase N availability during sorghum phase, and this will influence sorghum growth, development, and yield. The objectives of this study were to (i) evaluate how cropping system intensity affects residual nitrogen at sorghum planting and (ii) evaluate how cropping system intensity affects sorghum growth, development, and yield.

The Need for Sustainable Agriculture

The global population is expected to increase by over 9 billion by the year 2050 with an alarming 86% increase in urbanization and a nearly 20% decrease in rural area (FAO Director-General, 2009; Serraj and Pingali, 2019). The reason for urban swelling is largely due to economic growth and low agriculture productivity (Serraj and Pingali, 2019). Low agriculture productivity stems from the increasing wage-gap between rural and urban areas, which in turn further decreases productivity by reducing employment and profit. This is of great concern, given that large amounts of land will be taken out of production to accommodate global expansion. As a result, the agricultural community is forced to deal with this growing concern. One of the issues that growers will have to face is trying to produce nearly twice the amount of food, with limited land to do so. With a limited land resource, the margin of error becomes virtually non-existent, and terms such as preservation and stewardship become crucial. Another issue that weighs heavily on agriculture is the topic of climate change.

Climate change is a hot topic in today's society and for good reason. This term represents a shift in earth's climate as a result of human activities and the production of greenhouse gasses (GHG) (Jay et al., 2018). GHG, which will be described later, are simply gasses that capture and redistribute heat (Brander, 2012). These gasses are either produced naturally in the environment or accelerated during human activities. Regardless of where these gasses originate, all contribute to the shifting climate that directly impacts growers.

This climatic shift brings about extreme weather patterns that threaten agriculture production. These extreme weather patterns consist of high temperatures, droughts, and floods (Gowda et al., 2018). With higher temperatures comes yield decline, due to temperature reaching above the maximum temperature threshold of certain crops. Not only do high temperatures reduce yield, they also prolong drought periods that also prove disastrous. Prolonged drought contributes to poor yields as well as depletion of water resources. When droughts are experienced, producers rely heavily on irrigation to meet crop demands. In doing so, water reservoirs are being diminished as well as projected irrigated acres, due to water availability. On the other side, climate change is forecasted to escalate extreme rainfall events, which in turn creates the problem of erosion from agricultural lands. This loss of sediment is not only detrimental to producers because of loss of stored nutrients, but the environment as well creating problems with fresh water and animal life. With crop quality declining as a result of climatic change, water availability, and the reduction in land use, the hardship of feeding an expanding population becomes evident. Though climate change is underway and cannot be fully stopped, there are mitigation strategies that can help to alleviate its full impact. Research continues to improve cropping system sustainability and reduction in GHG through the use of crop rotation and cover crops.

Though crucial and abundant, N was available only in materials such as animal manure and previous crop organic matter, which had limited use during the season. It wasn’t until the early 1900’s when two scientists revolutionized agriculture (Brightling, 2018). The Haber and Bosch process for synthesizing ammonia has become an essential component of modern agriculture and has been utilized and improved on since its first introduction (Brightling, 2018). Being able to apply N whenever and as many times as needed, is not only beneficial but vital. In fact, according to Scharf (2015), 40% of the population would not be alive today without industrially synthesized ammonia.

Since the introduction of ammonia synthesis, improvements have been made to produce the product more efficiently with less energy and lower emissions. While all the nitrogen (N) utilized in this process comes from the air, hydrogen on the other hand is extracted from one of two ways. Such processes include either i) using natural gas or light compounds or ii) using oil or coal through chemical reactions. (Brightling, 2018). Of these 2 extraction methods, using natural gas is the most energy-efficient (28 GJ $t^{-1}NH_3$) with the lowest emissions (1.6 tonnes $t^{-1}NH_3$), while using coal requires the most energy (42 GJ $t^{-1}NH_3$) with the highest emissions produced (3.8 tonnes $t^{-1}NH_3$) (Brightling, 2018). Synthesizing ammonia efficiently is of great importance, given the fact that production has and continues to rise each year to meet the demands of the growing population. However, energy-efficient production of ammonia is reaching maximum capabilities. Therefore, other alternatives, such as cover crops and crop rotations, should be utilized to help improve the sustainability and performance of cash crops within cropping systems.

Cover Crops

Aside from planting and termination, cover crops are essentially a hands-free tool that can be utilized in cropping systems to provide multiple benefits. Cover crops, by the most basic definition, are short term rotations that aid in soil conservation (Reeves, 1994; Sharma et al., 2018). Typically, cover crops are planted between cash crops and are not intended for harvest and include species such as legumes, brassicas, and grasses (Clark et al., 2007; SARE 2012; White, 2014). Different cover crops have different functions. For instance, leguminous plants biologically fix atmospheric N (Blanco-Canqui et al., 2015) through a symbiotic relationship with bacteria known as rhizobia (Lamb et al., 2014). Leguminous N fixation can provide considerable amounts of N within the soil profile and potentially reduce N fertilizer needs of cash crops. Depending upon variables such as species, weather, and soil conditions, the N contribution from legumes to a subsequent grain crop can range from as little as 20 pounds acre^{-1} to more than 300 pounds acre^{-1} (Caddel et al., 2017). Hermanson et al. (2000) reported that agronomic crops typically uptake between roughly 30 to 70% of fertilizer N. It is important to note that the planting of leguminous cover crops require inoculum of the bacteria for maximum efficiency (SARE, 2012). Non-legume cover crops, such as brassicas and grasses, are better suited for sequestering nutrients, reducing erosion, conserving soil moisture, improving yields, and suppressing weeds (Clark, 2007). With cover crops having different abilities, a grower must identify the goal(s) they want to accomplish, which will help decide what cover crop to grow (Blanco-Canqui et al., 2015). Not only does a grower have to identify the goals they wish to accomplish, but they must also account for the region in which they live to make an accurate choice. Regions vary in weather, soil type, and crop rotations, all of which will influence the type of cover crops grown. Once these two aspects are accomplished, the better success a grower will have with cover crops. Negligence on the growers' behalf to inadequately research these areas, could result in poor cover crop performance as well as problems within the system (Clark, 2007). Aside from cover crops costing money to plant and terminate, they also have the potential to deplete soil water through transpiration, leading to yield reductions of the following cash crop (Reeves, 1994).

A number of studies have reported positive results of cover crops in cropping systems. Nagumo (2005), grew mucuna bean (*Mucuna pruriens*) as a cover crop after grain sorghum (*Sorghum bicolor* L.), on Ishigaki Island, Japan, using a no-till system. The author found that there was a 95% decrease in soil loss when a combination of mucuna bean and no-till were present vs tillage and the absence of mucuna bean. The authors noted a significant reduction in total dry matter of weeds with a combination of no-till and mucuna bean compared to all tillage treatments. In a similar study that added only one cover crop, Damian et al. (2017), grew black oats (*Avena strigose* L.) as a cover crop preceding soybeans (*Glycine max* L.) in a no-till system. Nutrients such as N, phosphorus (P), and magnesium (Mg) gathered by black oats, not only altered fertilizer regimes, but also influenced soybean yield. In both studies, multiple benefits were observed from the addition of only one cover crop. Mixtures of multiple species have been proposed as a way to provide even more benefits (Blanco-Canqui et al., 2013).

Many of the benefits resulting from cover crops have been associated with increases in soil organic matter (SOM), which contains soil organic carbon (SOC) (Blanco-Canqui et al., 2011). In an extensive review of over a hundred studies and 372 sites over multiple countries, regions, and management practices, Abdalla et al. (2019) reported that both legume and non-legume cover crops significantly increased SOC when compared to control treatment. Blanco-Canqui et al. (2013) replaced a fallow period with winter triticale (*xTriticosecale* Wittm.), winter lentil (*Lens culinaris* Medik.) , spring lentil, spring pea (*Pisum sativum* L. ssp.), and spring triticale cover crops in a no-till winter wheat system in the Central Great Plains. On average, triticale species and spring lentil increased SOC by 1.2 times compared to fallow. Hubbard et al. (2013) reported SOC increases of 32 to 43% by intensifying no-till sweet corn system with crimson clover (*Trifolium incarnatum*) and sunn hemp (*Crotalaria juncea*) cover crops grown under different rotations. Sainju et al. (2018) reported that SOC was 6 to 11% greater with a hairy vetch (*Vicia villosa*) and rye (*Secale cereale*) mixture grown before forage sorghum compared to rye or hairy vetch grown alone and the control. Higashi et al. (2014) reported increases in SOC of 5.6 to 6.8% with a hairy vetch cover crop and 15.6 to 17.2% with a rye cover crop compared to fallow. Mazzoncini et al. (2011) grew non-legume, high N legume, and low N legume cover crops in rotations with corn (*Zea mays*) and durum wheat (*Triticum durum*) from 1994 through 2008. Overall, legume cover crops increased SOC by 10% in the 0-4 in depth and 8% in the 4-12 in depth compared to the no-cover crop control. Non-legume cover crops increased SOC at both depths, but less than legumes and not significantly different from the control. Garcia-Gonzalez et al. (2018) grew corn and sunflower (*Helianthus annuus* L.) with the incorporation of vetch and barley (*Hordeum vulgare* L.) cover crops during fall and winter months. They reported that SOC increased by 1.6% in the 0-5 cm depth from barely and vetch, but no difference was observed at depths beyond 5 cm.

Greater SOC and SOM often are associated with improved soil aggregation. Mpeketula and Snapp (2019) studied the effects of grain crop (corn, soybean (*Glycine max*), and wheat) rotations, fertilizer source, and cover crops on soil structure. After 20 years (1993-2013), synthetic fertilizer, compost, and crop diversity all positively influenced macroaggregates and microaggregates. At the shallowest depth (0-2 in), rotations with the highest diversity (including cover crops) coupled with compost, lead to the greatest mean weight diameter (0.029 in). In rotations with the same diversity, substituting synthetic fertilizer for compost showed a mean weight diameter of only 0.024 in. The smallest mean weight diameter was recorded in continuous corn using synthetic fertilizer, reaching only 0.016 in. Similar results were obtained by Shaver et al. (2002), who looked at crop rotations (wheat and corn) and their effects on soil physical properties. Although there were variations, it was concluded that continuous cropping had the highest level of pores with wheat-corn-fallow rotation behind it, and wheat-fallow having the lowest.. Although there were variations, both continuous cropping and wheat-corn-fallow rotations had greater macroaggregates compared to wheat-fallow, proving that cropping intensity increases soil physical properties. Garcia et al. (2013) had rotations consisting of grain sorghum and ruzigrass (*Brachiaria ruziziensis*), that were grown individually, and then a grain sorghum plus ruzigrass mixture that were all grown during the fall/winter months. The spring months included three cover crops consisting of pearl millet (*Pennisetum glaucum*), sunn hemp, and sorghum-sudan (*Sorghum bicolor x S. bicolor var. sudanense*) that were grown ahead of soybeans. Only soil physical properties were studied for this experiment. Results showed that spring cover crops proved effective at increasing porosity and decreasing bulk density. Fall/winter cover crops on the other hand, proved relatively ineffective at changing soil physical properties. Calonego et al. (2017) grew either triticale or sunflower as fall and winter cover, and pearl millet, forage sorghum, and sunn hemp were as spring cover crops in a continuous soybean system in Botucatu, Brazil. Control treatment consisted of a fallow period with the addition of tillage via chiseling every six years (2003, 2009, and 2013) before soybean planting. Total porosity and macroporosity were greater after the first tillage operation but cover crop species had no effect. However, these immediate benefits observed from chiseling were short-lived, and after 2 years of cover crop establishment, the authors reported an increase in macroporosity and yield. After 12 years of this experiment, soybean yields increased by 23 to 32% when cover crops were present compared to chiseled plots. Santos et al. (2015) found similar results with cover crop treatments consisting of individual species (black oats or wheat) or a mixture (black oats, turnips, and vetch) planted during winter months before a soybean cash crop. Results showed that all cover crops, whether it be individual species or mixtures, lead to reduced macroporosity over the applied area compared to the control (fallow). Individual species reduced macroporosity by 77% (wheat) and 86% (black oats) over the entire area, while cover-rop mixtures reduced macroporosity by 42% (turnips and black oats) and 32% (black oats, turnips (*Brassica rapa subsp. rapa*), and common vetch) of the entire area. These results disagree with

Nicoloso et al. (2008), who found increases in soil macroporosity from using cover crops (black oats and forage radish (*Raphanus sativus var. oleiformus*).

Enhancing soil aggregate stability and increasing pore size can in-turn lead to an increase in infiltration and percolation (Çerçioğlu et al., 2019). Although adding a cover crop to the system under drought conditions can deplete the soil profile, it can also add resilience to the system. Daigh et al. (2014) showed that including a rye cover crop planted in October of 2011 in a corn-soybean rotation during the 2012 drought resulted in an increase in soil water content during early growth of the subsequent cash crop at a site in Iowa. In the same study, two sites in Indiana had no increase nor decrease in soil water content with the addition of the rye cover crop. Cash crop yield was not reported, as it was not the main focus of this study. In a similar study, Villamil et al. (2006) grew a corn-soybean no-till rotation with cover crops in Urbana, IL. Rye was always grown after corn, and either vetch, rye, or a vetch rye mixture was grown after soybeans. Results showed that with the inclusion of cover crops, bulk density was reduced by 7% at the 0 to 2 in depth, and the sequence, including vetch was the only one capable of significant reductions in bulk density at the 2-4 in depth. No significant effect on bulk density was observed once depth surpassed 4 in for any rotation. As a result of decreased bulk density, porosity at the soil surface was increased, resulting in greater water retention compared to fallow. Water aggregate stability increased by 9% with rye, 13% for rye and vetch, and rye-vetch mixture. After 15 years of either hairy vetch, sunn hemp, or late maturing soybeans in a no-till wheat-sorghum system on a silt loam soil, Blanco-Canqui et al. (2011) reported that cover crop treatments increased infiltration by up to a factor of three and increased soil water content by 35% compare to the treatment without cover crops. Similar results were observed by Nouri et al. (2019), who inserted hairy vetch and winter wheat cover crops into a cotton (*Gossypium* *hirsutum*) production system in the southeast. The hairy vetch cover crop improved wet aggregate stability by 13% and lead to an increase in the moisture content of 28.6 and 36.4% compared to the control. Moisture content was obtained from soil cores taken to a depth of 12 in in July after the cotton had been planted. Cumulative infiltration rate was increased with both vetch and winter wheat cover crops. The greatest infiltration occurred with the vetch cover crop combined with no-till, reaching 5.4 in h^{-1}, and the wheat cover crop had an intermediate effect reaching 4.7 in h^{-1}. Cumulative infiltration for the treatment with no cover crop was 2.5 in h^{-1}.

Grain Sorghum

Grain sorghum response to cover crops

Grain Sorghum is an important cereal crop that is ranked 5th globally and is comprised of 5 different races (Mundia et al., 2019; Ciampitti and Prasad, 2019). These races include bicolor, guinea, caudatum, kafir, and durra (Mundia et al., 2019; Ciampitti and Prasad, 2019). Of these five races, bicolor is the typical race used for commercial purposes (Mundia et al., 2019), and was the race used in this study. Sorghum, unlike other crops, have unique qualities that allow it to be grown in areas where other crops would fare poorly. Sorghum is typically grown in areas that experience lower rainfall events and higher temperatures on a broad scale of soils (Mundia et al., 2019; Baligar and Fageria, 2007). While most crops prefer a narrower pH, sorghum can be grown on a pH ranging from 5 to 8.5 (Baligar and Fageria, 2007). In addition to these previous attributes, sorghum is well known for its drought tolerance (Mundia et al., 2019; Baligar and Fageria, 2007).

Overall, sorghum is a unique and versatile crop that allows it to be grown across the globe. The region where it is grown determines its use in society. On continents such as Africa and Asia (China and India), sorghum is primarily used for human consumption, while North America and Australia primarily use sorghum for livestock feed (Mundia et al., 2019; Ciampitti and Prasad, 2019). Recently in the US, around 40% of the sorghum harvested is now being used for the production of ethanol (Mundia et al., 2019; Ciampitti and Prasad, 2019). Given all the attributes of sorghum, it would seem like a viable option for crop rotations, compared to other crops, when abiotic stresses prove challenging.

Crop rotations have been around since antiquity and are defined as a series of crops grown in succession over a given period of time (Reeves, 1994; Castellazzi et al., 2008). Crop rotations are put into place due to the benefits they provide. These benefits include aspects such as increased N, SOM and water retention, and an increase in soil structure (Castellazzi et al., 2008). In addition, when different crop species are grown in succession, weed, disease, and insect cycles are disrupted due to pests developing a narrow host range (Reeves, 1994). Crop rotations not only include regular cash crops but cover crops as well, and depending on the growers' intentions, can provide cover year around.

Several studies have documented positive responses of grain sorghum to cover crops, often resulting from greater N available to the sorghum when cover crops were included. Blanco-Canqui et al. (2012) studied different effects of a winter wheat-grain sorghum rotation at Hesston, KS. Cover crops consisted of hairy vetch (1995-2000), late-maturing soybean (2002-2009), and sunn hemp (2002-2009). From 2000-2002, no cover crops were grown, and wheat was planted over the entire area. The authors reported that soil N concentration was increased by 230 pounds acre^{-1} with late-maturing soybeans and 249 pounds acre^{-1} with sunn hemp compared to control. Reinbott et al. (2004) had two experiments, one in corn and one in sorghum in rotations with cover crops near Colombia, MO. Cover crop rotations included oat (*Avena sativa*), hairy vetch, Austrian winter pea, different seeding rates, and with various species mixtures. Of the three cover crops, hairy vetch was the most successful at contributing N for both corn and sorghum (39 and 51 pounds acre^{-1}). Venkateswarlu et al. (2007) reported that the inclusion of horsegram (*Macrotyloma uniflorum*) in rotations of sorghum and sunflower significantly increased the amount of soil available N to a depth of 12 in. Neely et al. (2018) grew sorghum either with a cover crop (crimson clover) planted in fall, left fallow, or a sorghum-cowpea (*Vigna unguiculate*) intercrop in Overton, TX. The crimson clover proved effective at increasing soil N by 21% compared to fallow treatment. Ncube et al. (2007) studied the effects of sorghum rotation with cover crops (cowpea, pigeon pea (*Cajuns cajan*), groundnut (*Arachis hypogaea*), and Bambara groundnut (*Vigna subterranean*)) in Zimbabwe. Overall, the percent increase of N from legumes were 15-50% (2002/2003), 16-61% (2003/2004), and 29-83% (2004/2005). Sainju et al. (2018) grew forage sorghum in rotation with cover crops consisting of hairy vetch, rye, or a hairy vetch-rye mixture in Fort Valley, GA. The authors reported that soil ammonium content increased by 40% at the 5 to 15cm depth with the use of vetch and rye separately. Nitrate concentration also increased by 20% between the 0 to 12 in depth with vetch and the vetch-rye mixture.

Yield increases in sorghum resulting from rotations with other crops and cover crops have been documented in the scientific literature. Studies conducted in Nebraska by Kaye et al. (2007) and Sindelar et al. (2016) reported the effects of a sorghum-soybean rotation. Kaye et al. (2007) grew either continuous sorghum or sorghum rotated with nodulating or non-nodulating soybeans near Mead, NE. Fertilizer amendment consisted of either none, manure, or N. Without any fertilization, both nodulating and non-nodulating soybeans increased grain yield significantly over continuous sorghum. Though they both increased grain yield, it was found that nodulating soybeans increased yield by 31 % compared to non-nodulating soybeans. Sindelar et al. (2016) grew continuous corn, grain sorghum, and soybean or rotations either with grain crops or cover crops (oats/clover). When sorghum was grown with at least one other crop, a yield boost of 18 % was observed in all years except for one. The greatest yield increase without fertilizer was observed from the rotation: corn-soybean-grain sorghum-oat/clover mix improving sorghum yield by 18 to 248% increase compared to any other rotation.

Studies conducted in Africa have shown increases in yield under different management practices and rainfall distribution. Nansamba et al. (2016) studied the effects of grain sorghum rotation with cover crops (mucuna and cowpea), tillage practices, and fertilizer treatments at two sites in Uganda. At both sites, Bulegeni and IkiIki, grain yield increased with reduced till by 13 and 8.6 % compared to conventional. On average, yields at Bulegeni and IkiIki were 105 and 213 % greater when fertilizer treatments were applied compared to no fertilizer treatment. Furthermore, yields were greatest when manure was paired with N and P additions, representing a 134 % (Bulegeni) and 249 % (IkiIki) increase. Mucuna compared to cowpea, increased yield of sorghum by 14.4 % (IkiIki) and 10.9 % (Bulegeni). Though Obalum et al. (2011) did not grow a cover crop, yield increases were observed from just including mulch. The authors evaluated sorghum either with no-till or conventional till and either a mulch (leaves) or left bare in Nigeria. Yield increases of 26%were identified in mulched plots compared to bare plots. When year was weighted and averaged, yield increased in no-till bare (53%), no-till mulch (53%), and conventional till mulch (67%) compared to conventional till bare. Bado et al. (2012) grew sorghum in rotation with cotton and groundnut in Guinea. Rotations consisted of cotton-groundnut-sorghum, fallow-sorghum, or sorghum-sorghum. The authors concluded that the full rotation produced the highest grain yields, and the sorghum-sorghum rotation had the lowest yields. Incorporating groundnut or leaving the land fallow increased mean annual grain yields of sorghum by 1.7 and 1.9 times.

History and agriculture use of nitrogen fertilizer

While N is crucial for life and abundant within the atmosphere (79% of total air), it does not exist in a form available to plants (Lamb et al. 2014). However, leguminous plants can convert atmospheric N into a plant-useable form. This relationship is a great source of adding N to cropping systems, though the amount of N supplied depends upon environmental and management factors (Reeves 1994). Which if adverse environmental conditions or management decisions are experienced, the N supply from cover crops will be reduced. Hence the need for the additional N source made possible by Haber and Bosch. As metioned above, this break through was a huge success and a pivotal moment for the agricultural community.

The impacts of synthetic N fertilizers in cropping systems have been well documented. Mourtzinis et al. (2017) and Videnovic et al. (2013) conducted similar studies assessing the effects of N fertilizer rates in a maize-soybean-wheat rotation. Though yield differences were observed between N rates, it was consistent in both studies that rotation between crops rather than continuous cropping led to better yields. Videnovic et al. (2013) concluded that although there were variations, all fertilizer treatments except control (0 pounds acre^{-1}) lead to greater yields, though continuous cropping had the lowest yields overall compared to other treatments. The most intensive rotation led to the greatest yields among all rotations. Mourtzinis et al. (2017) addressed N interaction, rotation, and the impact on yield. Again, results varied between different variables, but yields generally increased with rotation and increasing N rate compared to control. Wheat yield was strongly correlated to N rate, and the lowest yields were obtained in plots with 0N, regardless of rotation.

Grain sorghum response to nitrogen fertilizer

Sorghum is one of the major cash crops grown in Kansas due to its drought tolerance and functionality under high temperatures. With precipitation being a key component for nutrient travel through the soil to the root, it raises the question regarding how much N fertilizer is required for optimal performance in different cropping systems. Higher N rates typically result in higher yields. Abuneyewa et al. (2017) grew sorghum with different row arrangements and populations in Lincoln, NE. Conventional planting produced higher yields with increasing N rates from 0 up to 134 pounds acre^{-1}. The skip row arrangements produced higher yields with an N rate of 45 pounds acre^{-1}, though exceeding past 45 pounds acre^{-1} showed no yield increase. Among the skip row arrangements, alternate row planting had the highest yields compared to 2 rows planted following two rows skipped, though both had lower yields compared to conventional planting. Split applications of N at different growth stages can allow for more precise use by the plant. Jung et al. (2016), studied varying N rates and split N applications at different sorghum growth stages and showed that higher N applications resulted in better plant attributes when compared to 0 N. Application of 267 pounds acre^{-1} N resulted in 19,341 pounds acre^{-1} of total dry matter, whereas 0 N resulted in 8,955 pounds acre^{-1}. No benefits were observed for the split applications, no matter what growth stage the N was applied or the amount. This was probably the result of lower than normal precipitation during the experimental period.

Hypothesis and Objectives

We hypothesized that increasing cropping intensity during the fallow period between wheat and sorghum will increase N availability during sorghum phase, and this will influence sorghum growth, development, and yield. The objectives of this study were to (i) evaluate how intensity affects residual inorganic profile N and (ii) evaluate how intensity affects sorghum growth, development, and yield.

References

Abdalla, M., A. Hastings, K. Cheng, Q. Yue, D. Chadwick, M. Espenberg, J. Truu, R.M. Rees, and P. Smith. 2019. A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. Global Change Biol. 25(8): 2530–2543. doi:10.1111/gcb.14644

Abunyewa, A.A., R.B. Ferguson, C.S. Wortmann, and S.C. Mason. 2017. Grain sorghum nitrogen use as affected by planting practice and nitrogen rate. J. Soil Sci. Plant Nutr. doi:10.4067/s0718-95162017005000012

Bado, B.V., A. Bationo, F. Lompo, K. Traore, M.P. Sedogo, and M.P. Cescas. 2012. Long term effects of crop rotations with fallow or groundnut on soil fertility and succeeding sorghum yields in the Guinea Savannah of West Africa. Lessons learned from Long-term Soil Fertility Management Experiments in Africa:27–40. doi:10.1007/978-94-007-2938-4_2

Baligar, V.C., and N.K. Fageria. 2007. Agronomy and physiology of tropical cover crops. J. Plant Nutr. 30:1287-1339. doi:10.1080/01904160701554997

Blanco-Canqui, H., J.D. Holman, A.J. Schlegel, J. Tatarko, and T.M. Shaver. 2013. Replacing fallow with cover crops in a semiarid soil: Effects on soil properties. Soil Sci. Soc. Am. J. 77:1026-1034.

Blanco-Canqui, H., M.M. Claassen and D.R. Presley. 2012. Summer cover crops fix nitrogen, increase crop yield, and improve soil–crop relationships. Agron. J. 104:137-147.

Blanco-Canqui, H., M.M. Mikha, D.R. Presley, and M.M. Claassen. 2011. Addition of cover crops enhances no-till potential for improving soil physical properties. Soil Sci. Soc. Am. J. 75:1471-1482.

Blanco-Canqui, H., T.M. Shaver, J.L. Lindquist, C.A. Shapiro, R.W. Elmore, C.A. Francis, and G.W. Hergert. 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. Agron. J. 107:2449-2474.

Brander, M. 2012. Greenhouse Gases, CO2, CO2e, and Carbon: What Do All These Terms Mean? Ecometrica. https://ecometrica.com/assets/GHGs-CO2-CO2e-and-Carbon-What-Do-These-Mean-v2.1.pdf

Brightling, J. 2018. Ammonia and the Fertiliser Industry: The Development of ammonia at Billingham. Johnson Matthey Technology Review 62(1):32–47. doi:10.1595/205651318x696341

Caddel, J., Redfearn, D., Zhang, H., Edwards, J., and Deng, S. 2017. Forage legumes and nitrogen production. Oklahoma Cooperative Extension Service PSS-2590 [Online]. Available at https://extension.okstate.edu/fact-sheets/forage-legumes-and-nitrogen-production.html (verified 22 April 2020).

Calonego, J.C., J.P. Raphael, J.P. Rigon, L.D.O. Neto, and C.A. Rosolem. 2017. Soil compaction management and soybean yields with cover crops under no-till and occasional chiseling. Eur. J. Agron. 85: 31–37. doi:10.1016/j.eja.2017.02.001

Castellazzi, M., G. Wood, P. Burgess, J. Morris, K. Conrad, and J. Perry. 2008. A systematic representation of crop rotations. Agricultural Systems 97(1-2):26–33. doi:10.1016/j.agsy.2007.10.006

Ciampitti, I.A., and P.V.V. Prasad. 2019. Sorghum: a state of the art and future perspetives. American Society of Agronomy, Madison, WI.

Clark, A. (ed.). 2007. Managing cover crops profitably. 3rd ed. Sustainable Agriculture Network, Beltsville, MD.

Çerçioğlu, M., S.H. Anderson, R.P. Udawatta, and S. Alagele. 2019. Effect of cover crop management on soil hydraulic properties. Geoderma 343:247–253. doi:10.1016/j.geoderma.2019.02.027

xDaigh, A.L., M.J. Helmers, E. Kladivko, X. Zhou, R. Goeken, J. Cavdini, et al. 2014. Soil water during the drought of 2012 as affected by rye cover crops in fields in Iowa and Indiana. J. Soil Water Conserv. 69:564-573. doi:10.2489/jswc.69.6.564

Damian, J.M., A.L. Santi, M. Fornari, C.O.D. Ros, and V.L. Eschner. 2017. Monitoring variability in cash-crop yield caused by previous cultivation of a cover crop under a no-tillage system. Comput. Electron. Agric. 142:607–621. doi:10.1016/j.compag2017.11.006

FAO Director-General. 2009. FAOs Director-General on How to Feed the World in 2050. Population and Development Review. 35(4):837–839. doi:10.1111/j.1728-4457.2009.00312.x

García-González, I., C. Hontoria, J.L. Gabriel, M. Alonso-Ayuso, and M. Quemada. 2018. Cover crops to mitigate soil degradation and enhance soil functionality in irrigated land. Geoderma 322:81–88. doi:10.1016/j.geoderma.2018.02.024

Garcia, R.A., Y. Li, and C.A. Rosolem. 2013. Soil organic matter and physical attributes affected by crop rotation under no-till. Soil Sci. Soc. Am. J. 77(5):1724–1731. doi:10.2136/sssaj2012.0310

Gowda, P., J.L. Steiner, C. Olson, M. Boggess, T. Farrigan, and M.A. Grusak, 2018: Agriculture and rural communities. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 391–437. doi:10.7930/NCA4.2018.CH10

Hermanson, R., Pan, W., Perillo, C., Stevens, R., Stockle, C. 2000. Nitrogen use by crops and the fate of nitrogen in the soil and vadose zone: A literature review search. Washington State Department of Ecology.

Higashi, T., M. Yunghui, M. Komatsuzaki, S. Miura, T. Hirata, H. Araki, N. Kaneko, and H. Ohta. 2014. Tillage and cover crop species affect soil organic carbon in Andosol, Kanto, Japan. Soil Tillage Res. 138:64–72. doi:10.1016/j.still.2013.12.010

Hubbard, R.K., T.C. Strickland, and S. Phatak. 2013. Effects of cover crop systems on soil physical properties and carbon/nitrogen relationships in the Coastal Plain of southeastern USA. Soil Tillage Res. 126:276-283. doi:10.1016/j.still.2012.07.009

Jay, A., D.R. Reidmiller, C.W. Avery, D. Barrie, B.J. DeAngelo, A. Dave, M. Dzaugis, M. Kolian, K.L.M. Lewis, K. Reeves, and D. Winner, 2018: Overview. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. doi:10.7930/NCA4.2018.CH1

Jung, J.S., Y.-J. Kim, W.H. Kim, S.-H. Lee, H.S. Park, K.C. Choi, K.-W. Lee, T.-Y. Hwang, and G.-J. Choi. 2016. Effect of nitrogen fertilization levels and its split application of nitrogen on growth characters and productivity in sorghum × sudangrass hybrids [*Sorghum bicolor* (L.) Moench]. Journal of The Korean Society of Grassland and Forage Science 36(3):215–222. doi:10.5333/kgfs.2016.36.3.215

Kaye, N.M., S.C. Mason, D.S. Jackson, and T.D. Galusha. 2007. Crop rotation and soil amendment alters sorghum grain quality. Crop Science 47(2):722. doi: 10.2135/cropsci2006.05.0346

Lamb J.A., Fernandez F.G., Kaiser D.E. 2014. Understanding nitrogen in soils. University of Minnesota Extension. AG-FO-3770-B-(Revised 2014).

Mazzoncini, M., T.B. Sapkota, P. Bàrberi, D. Antichi, and R. Risaliti. 2011. Long-term effect of tillage, nitrogen fertilization and cover crops on soil organic carbon and total nitrogen content. Soil Tillage Res. 114(2):165–174. doi:10.1016/j.still.2011.05.001

Mourtzinis, S., D. Marburger, J. Gaska, T. Diallo, J.G. Lauer, and S. Conley. 2017. Corn, soybean, and wheat yield response to crop rotation, nitrogen rates, and foliar fungicide application. Crop Science 57(2): 983. doi:10.2135/cropsci2016.10.0876

Mpeketula, P.M.G., and S.S. Snapp. 2019. Structural stability conditions soil carbon gains from compost management and rotational diversity. Soil Sci. Soc. Am. J. 83(1):203. doi:10.2136/sssaj2017.03.0076

Mundia, C.W., S. Secchi, K. Akamani, and G. Wang. 2019. A regional comparison of factors affecting global sorghum production: The case of North America, Asia and Africa's Sahel. Sustainability 11(7):2135. doi:10.3390/su11072135

Nagumo, F. 2005. Actual state and perspectives of multipurpose cover crop research: Combination of mulch purpose cover crops with zero-tillage farming. JIRCAS international symposium series.

Nansamba, A., K.C. Kaizzi, A.B. Twaha, P. Ebanyat, and C.S. Wortmann. 2016. Grain sorghum response to reduced tillage, rotation, and soil fertility management in Uganda. Agron. J. 108(5):2137. 10.2134/agronj2015.0608

Ncube, B., S.J. Twomlow, M.T.V. Wijk, J.P. Dimes, and K.E. Giller. 2007. Productivity and residual benefits of grain legumes to sorghum under semi-arid conditions in southwestern Zimbabwe. Plant Soil 299(1-2):1–15. doi:10.1007/s11104-007-9330-5

Neely, C.B., F.M. Rouquette, C.L. Morgan, G.R. Smith, F.M. Hons, and W.L. Rooney. 2018. Integrating legumes as cover crops and intercrops into grain sorghum production systems. Agron. J. 110(4):1363. doi:10.2134/agronj2017.05.0293

Nicoloso, R.D.S., T.J.C. Amado, S. Schneider, M.E. Lanzanova, V.C. Girardello, and J. Bragagnolo. 2008. Eficiência da escarificação mecânica e biológica na melhoria dos atributos físicos de um latossolo muito argiloso e no incremento do rendimento de soja. Revista Brasileira de Ciência do Solo 32(4):1723–1734. doi:10.1590/s0100-06832008000400037

Nouri, A., J. Lee, X. Yin, D.D. Tyler, and A.M. Saxton. 2019. Thirty-four years of no-tillage and cover crops improve soil quality and increase cotton yield in Alfisols, Southeastern USA. Geoderma 337:998-1008. doi:10.1016/j.geoderma.2018.10.016

Obalum, S.E., U.C. Amalu, M.E. Obi, and T. Wakatsuki. 2011. Soil water balance and grain yield of sorghum under no-till versus conventional tillage with surface mulch in the Derived Savanna Zone of southeastern Nigeria. Exp. Agric. 47(1):89–109. doi:10.1017/s0014479710000967

Reeves, D.W. 1994. Cover crops and rotations. p. 125-172. In J.L. Hartfield and B.A. Stewart (eds.) Advances in soil science - crop residue management. Lewis Publishers, CRC Press, Boca Raton, FL, USA.

Reinbott, T.M., S.P. Conley, and D.G. Blevins. 2004. No-tillage corn and grain sorghum response to cover crop and nitrogen fertilization. Agron. J. 96(4):1158. doi:10.2134/agronj2004.1158

Sainju, U.M., H.P. Singh, B.P. Singh, A. Chiluwal, and R. Paudel. 2018. Soil carbon and nitrogen under bioenergy forage sorghum influenced by cover crop and nitrogen fertilization. Agrosyst. Geosci. Environ. 1:180004. doi:10.2134/age2018.03.0004

Santos, D.D., E.G.D. Souza, L.H.P. Nóbrega, C.L. Bazzi, and F.N.D. Queiroz. 2015. Physical properties of soils and soybean yields after planting cover crops. Engenharia Agrícola 35(2): 280–292. doi:10.1590/1809-4430-eng.agric.v35n2p280-292/2015

Scharf, P. 2015. Managing nitrogen in crop production. ACSESS Publications, Madison WI.

Serraj, R., and P.L. Pingali. 2019. Agriculture & food systems to 2050 global trends, challenges and opportunities. World Scientific Publishing Co. Pte. Ltd., Hackensack, NJ.

Sharma, P., A. Singh, C.S. Kahlon, A.S. Brar, K.K. Grover, M. Dia, and R.L. Steiner. 2018. The role of cover crops towards sustainable soil health and agriculture—A review paper. Am. J. Plant Sci. 09(09):1935–1951. doi:10.4236/ajps.2018.99140

Shaver, T.M., G.A. Peterson, L.R. Ahuja, D.G. Westfall, L.A. Sherrod, and G. Dunn. 2002. Surface Soil physical properties after twelve years of dryland no-till management. Soil Sci. Soc. Am. J. 66(4): 1296–1303. doi:10.2136/sssaj2002.1296

Sindelar, A.J., M.R. Schmer, V.L. Jin, B.J. Wienhold, and G.E. Varvel. 2016. Crop rotation affects corn, grain sorghum, and soybean yields and nitrogen recovery. Agron. J. 108(4):1592. doi:10.2134/agronj2016.01.0005

Sustainable Agriculture Research & Education. 2012. Types of Cover Crops [Online]. Available at https://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition/Text-Version/Cover-Crops/Types-of-Cover-Crops

Venkateswarlu, B., C. Srinivasarao, G. Ramesh, S. Venkateswarlu, and J.C. Katyal. 2007. Effects of long-term legume cover crop incorporation on soil organic carbon, microbial biomass, nutrient build-up and grain yields of sorghum/sunflower under rain-fed conditions. Soil Use and Manage. 23(1):100–107. doi:10.1111/j.1475-2743.2006.00068.x

Videnovic, Z., Jovanovic, Z., Dumanovic, Z., Simic, M., Srdic, J., Dragicevic, V., Spasojevic, I. 2013. Effect of Long-term crop rotation and fertilizer application on maize productivity. Turkish journal of Field Crops. 18(2):233-237

Villamil, M.B., G.A. Bollero, R.G. Darmody, F.W. Simmons, and D.G. Bullock. 2006. No-till corn and soybean systems including winter cover crops: Effects on soil properties. Soil Sci. Soc. Am. J. 70:1936-1944. doi:10.2136/sssaj2005.0350

White, P.A. 2014. The growing business of cover crops. National Wildlife Federation.

Chapter 2 - Cover crop biomass, C:N, and their effects on residual soil nitrogen

Abstract

Nitrogen (N) is one of the most essential and limiting nutrients in cropping systems. Cover crops have the potential to add N from either biological fixation (legumes) or sequestration (brassicas and grasses) during growth and release during decomposition. A field study was conducted to determine cover crop biomass, C:N ratio, and the effect on residual inorganic profile N in place of a fallow period between wheat harvest and sorghum planting in a no-till wheat-sorghum-soybean rotation. The experiment was conducted in a randomized complete block design with four treatments: chemical fallow (CF), double-crop soybeans (DSB), double-crop soybeans plus a spring cover crop before sorghum (DSBCC), and a summer cover crop mixure after wheat (CCMIX). Nitrogen (N) rates consisting of 0, 40, 80, 120, and 160 pounds acre^{-1} were subsurface banded after sorghum planting. Plant samples were taken at the time of cover crop termination to determine biomass and C:N ratio. Profile N samples were gathered to a depth of 24 inches before sorghum planting and were analyzed for nitrate and ammonium. When averaged across treatments, DSBCC accumulated roughly half as much biomass as CCMIX. When averaged over seasons, fall biomass produced by CCMIX had the greatest C:N, and spring biomass produced by CCMIX had the smallest C:N. Averaged over years, DSBCC and CCMIX treatments reduced profile inorganic N by 26 and 12 pounds acre^{-1} respectively compared to CF and DSB.

Introduction

Cover crops (CC) by the most basic definition are short-term, non-harvested crops grown between cash crops (Reeves, 1994). Typically, cover crops are grown for improving soil physical properties and are not intended for sale (Clark et al., 2007). There are two important aspects to point out with CCs: 1) cover crops are an investment, not an immediate source of benefits, and 2) cover crops must be carefully chosen by intended goals and region of the grower for maximum efficiency. Failure to do so will result in poor cover crop performance that can lead to poor cash crop performance. There are different types of cover crops, all with their own unique properties, and once growers identify the goal(s) and region, the right type of cover crop(s) can be easily identified.

Cover crops can be separated into different general groups: legumes, brassicas, and grasses (SARE, 2012; Clark et al., 2007). As mentioned above, leguminous plants have the ability to fix N, ranging from 20 pounds acre^{-1} to more than 200 pounds acre^{-1}, depending on certain variables. These plants form a symbiotic relationship with a type of bacteria known as rhizobia (Lamb et al., 2014). The bacterium takes N gas from the atmosphere and convert the gas into a useable form of N that the plants can utilize (Lamb et al., 2014). Once this bond is made, legumes such as hairy vetch and crimson clover, are capable of adding more than 100 pounds acre^{-1} of N (Reeves, 1994; SARE, 2012), and others such as field peas and red clover, typically add between 30 to 80 pounds acre^{-1} of N to the soil profile (SARE, 2012). While legumes are primarily chosen for their contribution of N, they have been documented to provide other amenities such as reducing erosion by 90-96% (Blanco-Canqui et al., 2015), increasing near-sruface soil organic carbon by 20-30% (Blanco-Canqui et al., 2011), and attracting beneficial insects (Baligar and Fageria, 2007; Balkcom and Reeves, 2005; Blackshaw et al., 2010; Clark et al., 2007; SARE, 2012). It is important to note that when planting legume cover crops, inoculum must be used for maximum efficiency.

The minor attributes of legumes are the major attributes of the brassica and grass type cover crops, with some additions. The brassica family is well known for rapid growth, biomass production, and the ability to scavenge nutrients through the soil profile (Clark et al., 2007). With the rapid growth and quick canopy closure, it allows brassicas to suppress a variety of small-seeded weeds such as Shepard's purse, green foxtail, and pigweed to name a few. In addition to weed suppression, brassicas are also known for gathering nutrients due to their root system, being able to reach depths of six feet or greater. One of the nutrients that brassicas scavenge for is N, which as mentioned above, is one of the most essential nutrients needed by all. Which, once the cover crop decomposes, it can release gathered nutrients and be readily available to a subsequent cash crop. Furthermore, the deep rooting system associated with this family allows for deeper channels into the soil profile. The channels allow for greater infiltration and percolation of irrigation or precipitation events. Which in turn, creates a larger reservoir for the subsequent cash crop and protects the crop if droughts are experienced. Aside from the listed attributes already mentioned, brassicas have gained increased attention due to their biological warfare against pests. The genetic makeup of these plants allows for toxic molecules to be secreted only when cells become damaged. These molecules behave as an allelopathic ability and fight against microorganisms, weeds, and insects, though this type of defense is less potent than synthetic chemicals (Clark et al., 2007; Rehman et al., 2018).

The last group of cover crops fall into the grass family. Grasses, much like brassicas, help to suppress weeds, scavenge nutrients, and have a deep rooting system (SARE, 2012). The caveat to these type of cover crops is the availability of N to the subsequent cash crop. Grasses, if left to reach full growth, produce a great deal of biomass with a high C:N ratio. The C:N ratio represents the amount of carbon relative to the amount of N within plants (USDA, 2011). For example if a plant has a C:N ratio of 20:1 that means that there are 20 parts of carbon to every 1 part of N. Microorganisms require about a C:N of about 24:1 to satisfy dietary requirements, and anything exceeding this ratio takes longer to decompose and requires an additional N source to meet the N demand of the microorganisms (USDA, 2011). The microorganisms acquire the additional N from the soil profile, and in doing so remove available N to the subsequent cash crop in a term known as immobilization (USDA, 2011). This naturally occurring phenomenon demands the use of synthetic fertilizers in order to meet the N demands of the following crop.

Regardless of the type of cover crop grown, all can aid in providing benefits to cropping systems. Though it should be mentioned that the benefits of cover crops are evident under optimum weather and soil conditions. If weather and soil conditions are outside or typical ranges, cover crop and cash crop performance will be less than ideal. Therefore, a grower must research weather patterns and assess soil moisture to ensure cropping system success. The objectives of this research were to i) evaluate how cropping system intensity affects cover crop biomass and C:N and ii) evaluate how intensity affects residual profile inorganic nitrogen at planting of the next cash crop.

Materials and Methods

Cover crop biomass sampling

Field trials were conducted from 2017 to 2019 within a long-term no-till wheat-sorghum-soybean rotation established in 2007 at the Kansas State University Department of Agronomy research farm located near Manhattan, KS (39.124037, -96.636469). The experimental design was a randomized complete block in a split-split plot arrangement with four replications. Crop phase (wheat, sorghum, or soybean) were the whole plots, fallow management treatments were the split plots, and N rates of 0, 40, 80, 120, or 160 pounds acre^{-1} applied at planting of the sorghum phase were the split-split plots. Each CC plot was 20 ft by 200 ft and subplots were 20 ft by 40 ft. Fallow-management treatments included: Control-Chemical fallow (CF), Double-crop soybeans (DSB), Double crop soybeans plus a spring CC planted in March and terminated before sorghum planting (DSBCC), and a CC mixture planted after wheat harvest and terminated by either freezing temperatures or with herbicide application before sorghum planting (CCMIX) (Table 2.1). Weather data was accessed from a weather station located approximately 800 ft from the center of the experiment (Kansas Mesonet, 2020).

All CCs were planted using a John Deere 1590 no-till drill (Deere and CO. Moline, IL). Cover crop biomass was sampled in the 2017, 2018, and 2019 seasons (Table 2.1). The CC treatment seeded in the summer after wheat harvest, CCMIX, was sampled near the time of the first killing freeze to assess summer and fall growth, and again in the spring before sorghum planting only if cool-season cover-crop species included in the seeding mixture survived the winter and produced additional biomass. The spring-seeded CC in the DSBCC treatment was sampled at the time of CC termination. Biomass production was determined by clipping all the aboveground plant material from a bordered 12.5 ft^2 area in each sub-plot. Samples were dried at 60° C for seven days. Dried samples were ground with a Wiley Mill (Thomas Scientific, Swedesboro, NJ) equipped with a 1 mm screen and subsequently analyzed to determine total C and N content using a LECO TruSpec CN combustion analyzer (TruSpec, St. Joseph, MI).

Profile N Sampling

Soil sampling to determine profile N content was conducted shortly after sorghum planting in the 2017, 2018, and 2019 seasons. All N subplots in the sorghum phase of the rotation where sampled each year (Table 2.1). Three cores per subplot were extracted to a depth of 24 in using a tractor-mounted soil probe equipped with a 1.5-inch sample tube (Giddings Machine Co., Windsor, CO). Soil samples were placed in a dryer at 60° C until dry. Dry samples were ground to a fine powder using a Nasco-Asplin soil grinder (Nasco, Fort Atkinson, WI) and placed in labeled containers. Samples were analyzed for inorganic N (NH_4^+ and NO_3^-) content using 1 M KCl extraction (Kowalenko, 2006). The amount of inorganic N available in the 0-24-inch profile was estimated as follows: pounds inorganic N acre^{-1} = 0.3 × sampling depth (inches) × ppm nitrate and ammonium-N (Leikam et al., 2003), where 0.3 converts the standard 2 million pounds acre furrow slice^{-1} (6.7-inch depth) to one inch assuming a consistent bulk density of 83.0 pounds foot^{-3}, which is not far from the 84.9 pounds foot^{-3} reported for the dominant soil series at this site (Web Soil Survey, 2020).

Analysis of variance was carried out for each year's data using SAS 9.4 PROC GLIMMIX with cover crop and N-rate treatments as fixed effects. Random variables consisted of replication and replication×cover crop. Least square means were separated by cover crop, N, and cover crop×N by pairwise comparisons when the probability of a greater F ≤ 0.05.

Results

Weather conditions

Total June to May precipitation was slightly above Normal (32.6 inches) in 2016-2017 (37.5 inches), below Normal in 2017-2018 (21.4 inches), and far above Normal in 2018-2019

(45.1 inches; Figure 2.1A). Normal is defined by National Oceanic Administration (2020) as the 30 year average of precipitation and temperature. The month of June, which was just before or at the time of double-crop soybean and CCMIX planting, experienced less than Normal precipitation all three seasons. As months progressed, 2016-2017 and 2018-2019 were above Normal from August through October, but 2017-2018 was less than Normal in September. During the winter months, 2016-2017 and 2018-2019 were either at or slightly above Normal precipitation. The 2017-2018 season was drier than Normal from November through May, receiving only an inch of precipitation during the months of November through February. During the spring months, at the time of spring cover crop planting and growth, precipitation in 2016-2017 and 2018-2019 were either at or above Normal. The 2017-2018 season remained lower than Normal for those months.

Air temperatures were less variable than precipitation, with all three seasons trending close to Normal (Figure 2.1B). The 2016-2017 season was warmer than Normal from August through November and from January through March. The only noticeable departures from Normal during the 2017-2018 season were cooler than Normal temperatures in July and August and again in April. Temperatures in 2018-2019 were relatively cooler than Normal from September through November and from January through March.

Double-crop soybeans

There was no significant effect of year×cover crop×N, year×N, cover crop×N, N, or cover crop on double-crop soybean seed yield (Table 2.2). However, the year×cover crop interaction and year effects were significant for seed yield; therefore, results are presented by year (Table 2.3). The 2016-2017 season was the only year with a significant difference between cover crop treatments when DSBCC had greater soybean yields than DSB. Although statistically significant, the three-bushel yield difference amounted to only a 6% change. Although double-crop soybean yields were two bushels acre^{-1} greater in 2018-2019 compared to 2017-2018, yields in 2016-2017 were double the yields in 2018-2019 (Table 2.3).

Data for seed moisture and test weight were collected from only one level of N, so it does not appear in the over-year ANOVA (Table 2.2). Seed moisture response to cover crop interacted with year, so the results are presented by year (Table 2.3). The 2017-2018 season was the only season where double-crop soybean (DSB) harvest moisture had higher moisture conent than double-crop soybeans before cover cover treatment (DSBCC).. Averaged across treatments, the 2017-2018 season had the highest moisture content, with 2016-2017 season intermediate, and 2018-2019 lowest. Averaged over years, double-crop soybeans had higher grain moisture compared to double-crop beans harvested in the DSBCC treatment. Only a year effect was observed for test weight of harvested double-crop soybean grain with test weight decreasing each year (Table 2.3).

Cover Crop Biomass and C:N

The year×cover crop interaction significantly affected cover crop biomass, so results are presented by year (Table 2.2). Values for DSBCC and CCMIX spring cover crop biomass in the 2016-2017 season were estimated and were not included in the analysis of variance. Cover crop mixture had significantly greater fall biomass compared to spring biomass or double-crop soybeans plus spring cover crop biomass whenever valid comparisons could be made (Table 2.4). Cover crops produced twice the biomass in the 2018-2019 season compared to 2017-2018. The CCMIX had no spring biomass production in 2017-2018, and CCMIX fall biomass and DSBCC spring biomass yields were half that recorded in 2018-2019. Averaged over the 2017-

2018 and 2018-2019 seasons, CCMIX produced roughly twice the amount of biomass than the cover crop planted after double-crop soybeans in the DSBCC treatment (Table 2.4).

The cover crop biomass C:N ratio was significantly affected by the year×cover crop interaction (Table 2.2), so results are presented by year (Table 2.4). In the 2016-2017 and 2017-2018 seasons and averaged over seasons, the CCMIX fall biomass had the highest C:N ratio. However, in the 2018-2019 season, the cover crop mixture fall biomass had the lowest C:N ratio compared to the other two treatments. When averaged across cover crop treatments, 2016-2017 had the highest values, and 2017-2018 and 2018-2019 were not statistically different from one another (Table 2.4).

Soil profile N

There were no year×cover crop×N, year×N, or cover crop×N interactions observed for profile N (Table 2.2). There were, however, a year×cover crop interaction as well as a year effect that significantly affected profile N, therefore results are presented by year (Table 2.5, Figure 2.2). Cover crop effect within each year showed that the CCMIX treatment was statistically different from DSBCC only in 2018 and was statistically different from CF and DSB only in 2019. When looking at the cover crop effect over years, both DSBCC and CCMIX resulted in fewer pounds acre^{-1} of N at sorghum planting compared to CF or DSB (Table 2.5). The amount of N in the soil profile at sorghum planting in the DSBCC treatment was significantly less compared to that in CF, DSB, and CCMIX averaged over years. Pounds acre^{-1} of N in the 0-24-inch soil profile at sorghum planting decreased each year from 2017 to 2019 (Table 2.5).

Discussion

The exceptional growing season of 2016-2017, with double-crop soybeans reaching yields of 50 bushels acre^{-1} or better, was likely the result of weather conditions. From July to October, rainfall was greater than Normal, and from August to November, temperatures were hotter than Normal (Figure 2.1). In fact, Hansel et al. (2017) also indicates that weather experienced in the 2016 season was optimal for summer crops. Furthermore, yields obtained from Hansel's study found similar double-crop soybean yields of 50 bushels acre^{-1} or greater, from a study conducted in Ottawa, Kansas. Such weather conditions were similar to that of Raper et al. (2019), when late-season rainfall and higher temperatures lead to greater than normal double-crop soybean yields. Though yields of double-crop soybeans were impressive in 2016-2017 season, yields in all seasons were less than full-season soybeans. Results presented by Hansel et al. (2019) showed that yield of double-crop soybeans was less than that of full-season beans, but with a difference in magnitude with different varieties. In years where full-season soybeans reached 30, 30-40, and greater than 40 bushels acre^{-1}, yields of double-crop soybeans showed a 0.46, 6.3, and 16.6 bushels acre^{-1} reduction. Yields of double-crop soybeans in our study were closer to the 16.6 bushels acre^{-1} reduction reported by Hansel et al. (2019). Reductions in double-crop soybean yield were also found by Pfeiffer (2000) and Kyei-Boahen and Zang (2006). Though there were variations among experiments, both reduced yields between 10 to 40%.

The cover crop mixture (CCMIX) consisted of seven to eight species that had different seeding rates for each individual species, ranging from as low as 1 pound acre^{-1} to as high as 23.5 pounds acre^{-1}. The DSBCC on the other hand, consisted of only three species, which had seeding rates of 8 pounds acre^{-1} to 30 pounds acre^{-1}. The CCMIX in the spring either had estimated values (2017) or no values because winter cover crops did not survive (2018). Not only can the number of species be a possible explanation of greater biomass, but also the growing period between DSBCC and CCMIX could be a factor. The CCMIX is planted in the previous year and is sampled twice, once in the fall of the same year and again in the spring of the following year. The DSBCC however, is planted roughly one to two months prior to termination and sampling, resulting in a very short growing season. As a result of the number of species, sampling periods, and duration of growth, are all possible factors as to why cover crop biomass was greater for CCMIX. Another possible explanation as to why cover crop biomass was greater, could be linked to the amount of available soil N. Work done by Mazzocini et al., (2011) and Higashi et al., (2014) reported higher biomass accumulation with increased fertilizer rates. Pantoja et al., (2016) show that cover crop biomass was reduced because of limited N within the soil profile as well as a shortened growing period. The high C:N ratio for CCMIX in the fall of the 2016-2017 season was likely due to the greater production of sorghum-sudangrass in the mixture that year (data not shown). The C:N ratio in biomass and organic matter governs N cycling within crop residues and in the soil profile. Microorganisms require roughly a 24:1 ratio to meet dietary requirements (USDA, 2011). If the C:N ratio is greater, residue decomposition takes longer and ties up N from other sources to help breakdown residue, a process known as immobilization. Conversely, if the C:N ratio is less than 24:1, the residue decomposes more quickly, leading to a surplus of N that can be available more quickly.

Cover crops have the potential to reduce nitrate leaching and supply N to the subsequent cash crop (Thapa et al., 2018; Kaye et al., 2019). Although the effectiveness of this phenomenon depends upon numerous variables such as climate, soil type, cover crop species, and management practices (Thapa et al., 2018), it provides an effective way to reduce environmental risk and promote optimal crop growth. Our results showed that cover crops, specifically DSBCC, significantly affected inorganic N within the soil profile at sorghum planting, which has been reported in several other studies. In a meta-analysis comprised of 238 observations, 28 studies, and a mix of different cover crops, Thapa et al. (2018) found that non-legume covers reduced nitrate leaching by more than 50%, and mixtures of both legumes and non-legumes were just as effective. Restovich et al. (2012) found that growing numerous cover crops, much of which were similar to those evaluated in our experiment, resulted in a 50-90% reduction in nitrate depending on planting and killing date. Though our results show only 25% (DSBCC) and 13% (CCMIX) reductions of nitrate compared to the control, they still showed that cover crops were effective at reducing soil nitrate. Dean et al. (2009) reported that cover crops were successful at removing nearly all the nitrate down to a depth of one meter. Gabriel et al. (2012) studied the use of vetch and barley and their effects on leaching. For the duration of their study, the control leached 308 pounds acre^{-1} of nitrate, while barley and vetch leached 114 pounds acre^{-1} and 218 pounds acre^{-1} of nitrate, respectively. Kaye et al. (2019) grew legumes, brassicas, and grasses to study the effects of nitrate leaching. Though there were mixed results between species, all were successful at reducing nitrate leaching within the cropping system. All of these studies support our findings of reduced nitrate within the soil profile with cover crop, especially DSBCC, addition. For example, spring cover crops before sorghum (DSBCC) had 13 pounds acre^{-1} on average less nitrate compared to the cover crop mixture (CCMIX) (Table 2.5). This result is likely due to the actively growing cover crop over about two months before profile sampling occurred. The CCMIX had little or no active growth during this time (Table 2.4). Furthermore, results show that N fertilizer had no effect on profile N at any rate or year. This outcome is likely due to the fact that fertilizer rates were applied three years previously. The uniform fertilizer applications to wheat at 60 pounds acre^{-1} (2017) and 90 pounds acre^{-1} (2018, 2019), N fertilizer may have maintained profile N across all fallow-period treatments.

Conclusion

Inorganic N concentrations within the soil profile were significantly affected by the intensity of cover cropping in this experiment. Spring cover crop treatment (DSBCC) had a greater influence on reducing concentrations in all three years compared to CF and DSB. CCMIX reduced soil N concentrations in only one (2019) out of three years compared to CF and DSB. Nitrate is the only form of N in which N_2O emissions can originate (Clayton et al., 1997; Gillam et al., 2008). Emissions are generally aided by the use and incorporation of fertilizers and organic amendments (Hoben et al. 2010; Gregorutti and Caviglia, 2017; Tongwane et al. 2016; Groenigen et al. 2010). Nitrogen fertilizer applied to the sorghum crop had no effect on profile N, given that fertilizer rates were applied three years previously. As mentioned above, cover cropping intensity reduced overall nitrate levels. The CF and DSB treatments were separated by only four pounds acre^{-1} (when compared over years) with DSB being greater. The DSBCC treatment had on average 20 pounds acre^{-1} less than the CCMIX treatment between the 2017 and 2018 seasons. Reduced nitrate concentrations in the soil profile should lower N_2O emissions from cropping systems. Though this process would be environmentally friendly, the yield potential of the subsequent sorghum crop can be greatly diminished (Abunyewa et al., 2017), requiring carefully managed fertilizer inputs to meet crop demands.

References

Abunyewa, A.A., R.B. Ferguson, C.S. Wortmann, and S.C. Mason. 2017. Grain sorghum nitrogen use as affected by planting practice and nitrogen rate. J. Soil Sci. Plant Nutr. 17(1):155-166. doi:10.4067/s0718-95162017005000012

Baligar, V.C., and N.K. Fageria. 2007. Agronomy and physiology of tropical cover crops. J. Plant Nutr. 30:1287-1339. doi:10.1080/01904160701554997

Balkcom, K.S., and D.W. Reeves. 2005. Sunn-hemp utilized as a legume cover crop for corn production. Agron. J. 97(1):26–31. doi:10.2134/agronj2005.0026

Blackshaw, R.E., L.J. Molnar, and J.R. Moyer. 2010. Suitability of legume cover crop-winter wheat intercrops on the semi-arid Canadian Prairies. Can. J. Plant. Sci. 90(4): 479–488. doi:10.4141/cjps10006

Blanco-Canqui, H., M.M. Mikha, D.R. Presley, and M.M. Claassen. 2011. Addition of cover crops enhances no-till potential for improving soil physical properties. Soil Sci. Soc. Am. J. 75:1471-1482.

Blanco-Canqui, H., T.M. Shaver, J.L. Lindquist, C.A. Shapiro, R.W. Elmore, C.A. Francis, and G.W. Hergert. 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. Agron. J. 107:2449-2474.

Clark, A. (ed.). 2007. Managing cover crops profitably. 3rd ed. Sustainable Agriculture Network, Beltsville, MD.

Clayton, H., I.P. Mctaggart, J. Parker, L. Swan, and K.A. Smith. 1997. Nitrous oxide emissions from fertilised grassland: A 2-year study of the effects of N fertiliser form and environmental conditions. Biol. Fertil. Soils 25(3):252–260. doi:10.1007/s003740050311

Dean, J.E., and R.R. Weil. 2009. Brassica cover crops for nitrogen retention in the Mid-Atlantic Coastal Plain. J. Environ. Qual. 38(2):520–528. doi:10.2134/jeq2008.0066

Gabriel, J., R. Muñoz-Carpena, and M. Quemada. 2012. The role of cover crops in irrigated systems: Water balance, nitrate leaching and soil mineral nitrogen accumulation. Agriculture, Ecosystems & Environment 155:50–61. doi:10.1016/j.agee.2012.03.021

Gillam, K.M., B.J. Zebarth, and D.L. Burton. 2008. Nitrous oxide emissions from denitrification and the partitioning of gaseous losses as affected by nitrate and carbon addition and soil aeration. Can. J. Soil Sci. 88(2): 133–143. doi:10.4141/cjss06005

Gregorutti, V.C., and O.P. Caviglia. 2017. Nitrous oxide emission after the addition of organic residues on soil surface. Agriculture, Ecosystems & Environment 246:234–242. doi:10.1016/j.agee.2017.06.016

Groenigen, J.W.V., G.L. Velthof, O. Oenema, K.J.V. Groenigen, and C.V. Kessel. 2010. Towards an agronomic assessment of N2O emissions: a case study for arable crops. Eur. J. Soil Sci. 61(6):903–913. doi:10.1111/j.1365-2389.2009.01217.

Hansel, D. S.; Kimball, J.; Shoup, D. E.; and Ciampitti, I. A. 2017. Double Crop Soybean After Wheat. Kansas Agricultural Experiment Station Research Reports: Vol. 3:Iss. 6. https://doi.org/10.4148/ 2378-5977.7430

Hansel, D.S.S., R.A. Schwalbert, D.E. Shoup, D.L. Holshouser, R. Parvej, P.V. Prasad, and I.A. Ciampitti. 2019. A Review of Soybean Yield when Double-Cropped after Wheat. Agron. J. 111(2):677–685. doi:10.2134/agronj2018.06.0371

Higashi, T., M. Yunghui, M. Komatsuzaki, S. Miura, T. Hirata, H. Araki, N. Kaneko, and H. Ohta. 2014. Tillage and cover crop species affect soil organic carbon in Andosol, Kanto, Japan. Soil Tillage Res. 138: 4–72. doi: 10.1016/j.still.2013.12.010

Hoben, J.P., R.J. Gehl, N. Millar, P.R. Grace, and G.P. Robertson. 2010. Nonlinear nitrous oxide (N2O) response to nitrogen fertilizer in on-farm corn crops of the US Midwest. Global Change Biol. 17(2):1140–1152. doi:10.1111/j.1365-2486.2010.02349.x

Kaye, J., D. Finney, C. White, B. Bradley, M. Schipanski, M. Alonso-Ayuso, M. Hunter, M. Burgess, and C. Mejia. 2019. Managing nitrogen through cover crop species selection in the U.S. mid-Atlantic. Plos One 14(4). doi:10.1371/journal.pone.0215448

Kansas Mesonet. 2020. Weather Data Library. Kansas State University Agricultural Experiment Station. Manhattan, KS. Online: http://mesonet.k-state.edu/weather/historical/ (verified April 30, 2020)

Kowalenko, C.G. 2006. Evaluation of hot KCl extraction as an index of mineralizable N: Ammonium and ultraviolet absorption measurements. Can. J. Soil Sci. 86(5):911–920. doi: 10.4141/s06-047

Kyei-Boahen, S., and L. Zhang. 2006. Early-maturing soybean in a wheat-soybean double-crop system yield and net returns. Agron. J. 98(2):295–301. doi:10.2134/agronj2005.0198

Lamb J.A., Fernandez F.G., Kaiser D.E. 2014. Understanding nitrogen in soils. University of Minnesota Extension. AG-FO-3770-B-(Revised 2014).

Leikam, D.F., R.E. Lamond, and D.B. Mengel. 2003. Soil test interpretations and fertilizer recommendations. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. MF-2586.

Mazzoncini, M., T.B. Sapkota, P. Bàrberi, D. Antichi, and R. Risaliti. 2011. Long-term effect of tillage, nitrogen fertilization and cover crops on soil organic carbon and total nitrogen content. Soil Tillage Res. 114(2):165–174. doi:10.1016/j.still.2011.05.001

National Oceanic and Administration. 2020. Climate Normals [Online]. Available at: https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals.

Pantoja, J.L., K.P. Woli, J.E. Sawyer, and D.W. Barker. 2016. Winter rye cover crop biomass production, degradation, and nitrogen recycling. Agron. J. 108(2):841–853. doi:10.2134/agronj2015.0336

Pfeiffer, T. 2000. Selecting soybean for adaptation to double cropping on the basis of full season plant height. Crop Science 40(2):387–390. doi:10.21351cropsci2000.402387x

Raper, T.B., M.A. Mcclure, S. Butler, X. Yin, and R. Blair. 2019. Impacts of single- and a multiple-species cover crop on soybean relative to the wheat-soybean double crop system. Crop, Forage & Turfgrass Management 5(1):180104. doi:10.2134/cftm2018.12.0104

Reeves, D.W. 1994. Cover crops and rotations. p. 125-172. In J.L. Hartfield and B.A. Stewart (eds.) Advances in soil science - crop residue management. Lewis Publishers, CRC Press, Boca Raton, FL, USA.

Rehman, S., B. Shahzad, A.A. Bajwa, S. Hussain, A. Rehman, S.A. Cheema, T. Abbas, A. Ali, L. Shah, S. Adkins, and P. Li. 2018. Utilizing the allelopathic potential of brassica species for sustainable crop production: A Review. J. Plant Growth Regul. 38(1):343–356. doi: 10.1007/s00344-018-9798-7

Restovich, S.B., A.E. Andriulo, and S.I. Portela. 2012. Introduction of cover crops in a maize–soybean rotation of the Humid Pampas: Effect on nitrogen and water dynamics. Field Crops Research 128:62–70. doi:10.1016/j.fcr.2011.12.012

Sustainable Agriculture Research & Education. 2012. Types of Cover Crops [Online]. Available at https://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition/Text-Version/Cover-Crops/Types-of-Cover-Crops

Thapa, R., S.B. Mirsky, and K.L. Tully. 2018. Cover crops reduce nitrate leaching in agroecosystems:A global meta-analysis. J. Environ. Qual. 47(6):1400–1411. doi:10.2134/jeq2018.03.0107

Tongwane, M., T. Mdlambuzi, M. Moeletsi, M. Tsubo, V. Mliswa, and L. Grootboom. 2016. Greenhouse gas emissions from different crop production and management practices in South Africa. Environmental Development 19:23–35. doi:10.1016/j.envdev.2016.06.004

USDA Natural Resources Conservation Service. 2011. Carbon to nitrogen ratios in cropping systems [Online]. Available at https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd331820.pdf

Web Soil Survey. 2020. [Online] Available at https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (verified 2 May 2020).

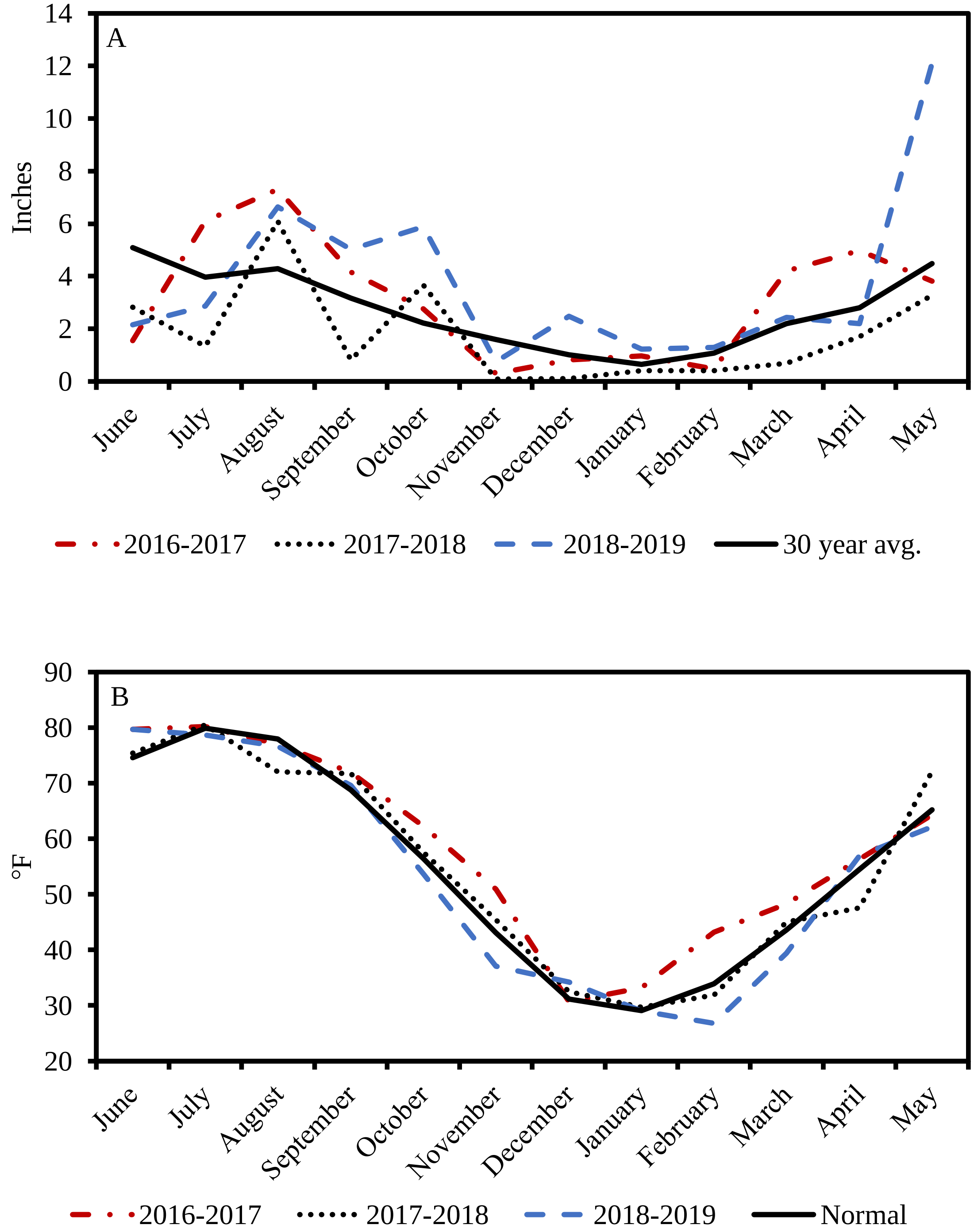


Figure 2.1. Monthly total precipitation (A) and average temperatures (B), compared to 1980-2010 Normals during double-crop soybean and cover crop growth and development at Manhattan, KS 2016 to 2019.

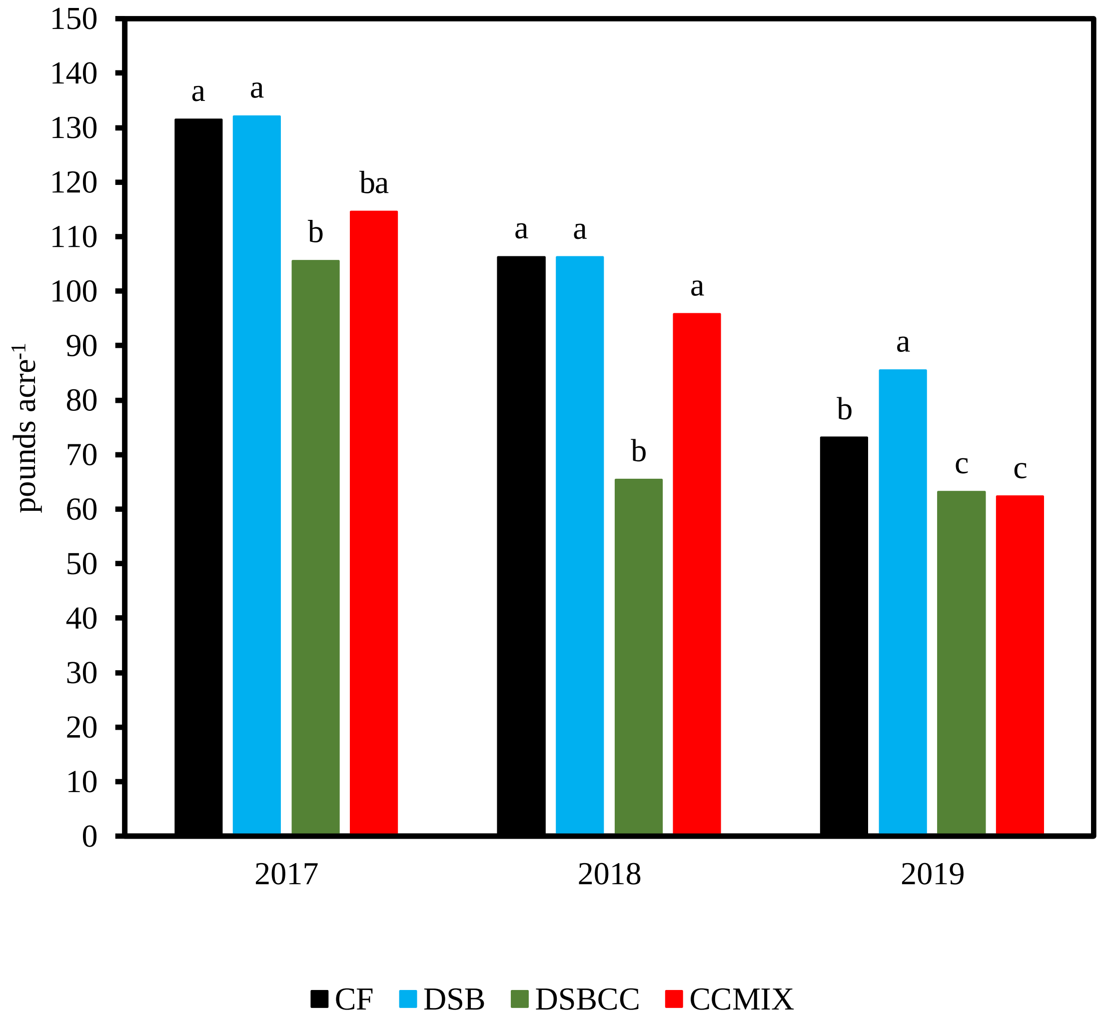


Figure 2.2. Inorganic nitrogen within the 0 to 24-inch soil profile at sorghum planting following cover-crop treatments (CF = chemical fallow, DSB = double-crop soybean, DSBCC = double-crop soybean plus spring cover crop, CCMIX = mixture of cover crop species) in a no-till soybean-winter wheat-sorghum rotation at Manhattan, KS 2017 to 2019. Treatment means within a year with the same lower-case letter above the bar are not significantly different (α = 0.05).

Table 2.1. Management practices for cover crop treatments evaluated for biomass production and residual soil profile N content at Manhattan, KS in 2017-2019.

Treatment (CODE) Management factor	2016	2017	2018	2019
Chemical fallow (CF) Burndown herbicide	6/23, 7/27, 9/8, 11/15	6/23, 7/14, 8/15, 10/15	6/28, 8/9, 9/15	-
Double-crop soybean (DSB)				
Herbicide applications	6/23, 7/27	6/23, 7/14, 7/29	6/28, 8/9	-
Planting date	6/29	6/26	6/27	-
Variety	AS4232	AS4232	KS3406	-
Seeds acre^{-1}	160,000	160,000	180,000	-
Harvest date	11/1	10/17	10/31	-
Double-crop soybean plus cover crop (DSB+CC)				
DSB component	←	Same as DSB treatment	→	-
CC component				
Planting date	-	11/1/2016	3/7	4/10
Species	-	———	lb acre^{-1}	———
Triticale	-	40	-	-
Rapeseed/turnip/radish	-	5	-	-
Oats	-	-	32	32
Field pea	-	-	30	30
Red clover	-	-	8	8
Sample date	-	4/26	5/21	6/3
Herbicide termination	-	4/27	5/22	6/3
Termination method	-	herbicide	herbicide	herbicide
Cover crop mix (CCMIX)				
Burndown herbicide	6/23	6/23, 7/14†, 7/29	6/28, 8/9	-
Planting dates	6/29	6/26, 8/1†	8-10	-
Species	———	lb acre^{-1}	———	-
Sorghum sudan	5‡	2.5§	2.5§	-
Cowpea	21‡	15§	15§	-
Late maturity soybean	-	23.5§	23.5§	-
Crimson clover	-	5	5	-
Daikon radish	4	2	2	-
Purple top turnip	2	1	1	-
Rapeseed	2	1	1	-
Biomass sample dates	9/20	10/31, 11/1	10-18	-
Roller/crimper‡	9/8	-	-	-
Frost termination§	11/12	10/28	10/24	-
Herbicide termination	4/27/2017	3/8/2018	6/4/2019	-
Profile N sample dates	-	6/5 – 8	5/29, 6/5	6/17 – 18

†Initial CC planting terminated and replanted due to heavy weed infestation.
‡Roller/crimper stopped growth of indicated species but did not kill them.
§Freezing temperatures on these dates killed indicated species.

Table 2.2. Tests of significance for cover crop response to main effects of year, cover crop, nitrogen rate, and their interactions in a no-till three-yr sorghum-soybean-wheat/cover crop rotation at Manhattan, KS for the 2016-2019 seasons.

	Source of Variation						
Response variable	Cover crop (CC)	Nitrogen (N)	CC×N	Year (Y)	Y×CC	Y×N	Y×CC×N
	———————— Probability of >F ————————						
Double-crop soybean							
Seed yield	0.213	0.784	0.219	<0.001	0.007	0.970	0.835
Seed moisture†	0.003	-	-	<0.001	0.002	-	-
Seed test weight†	0.637	-	-	<0.001	0.962	-	-
Cover crop							
Biomass yield	<0.001	0.758	0.995	<0.001	0.022	0.305	0.711
CN	<0.001	0.828	0.992	<0.001	<0.001	0.917	0.887
Profile N	<0.001	0.810	0.845	<0.001	<0.001	0.668	0.887
2017	<0.001	0.363	0.893	-	-	-	-
2018	<0.001	0.953	0.495	-	-	-	-
2019	<0.001	0.801	0.421	-	-	-	-

† Data were not available for different nitrogen rates, so only cover crop, year, and their interaction were tested.

Table 2.3. Yield of double-crop soybean planted between wheat and sorghum in a no-till three-yr sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2016 to 2018.

Response variable Season	DSB[†]	DSBCC	Season mean
	bushels a^{-1}		
Yield			
2016-2017	50 b[‡]	53 a	52 A[§]
2017-2018	23 d	25 cd	24 C
2018-2019	27 c	25 cd	26 B
Treatment mean	34	34	
Grain moisture	%		
2016-2017	12.3 b	12.2 b	12.2 B
2017-2018	14.0 a	11.8 b	12.9 A
2018-2019	8.2 c	8.1 c	8.1 C
Treatment mean	11.4 A	10.7 B	
Grain test weight	pounds $bushel^{-1}$		
2016-2017	58.1	58.2	58.2 A
2017-2018	54.6	54.8	54.7 B
2018-2019	52.2	52.3	52.2 C
Treatment mean	55.0	55.1	

[†] DSB: Double-crop soybeans, DSBCC: Double-crop soybeans plus a spring cover crop before sorghum planting.

[‡] Interaction means followed by the same lower-case letter do not differ (α = 0.05).

[§] Main-effect means followed by the dame upper-case letter do not differ (α = 0.05).

Table 2.4. Biomass yield and quality of cover crops planted between wheat and sorghum in a no-till three-yr sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2016 to 2019.

Response variable Season	Fallow Management treatments[†] DSBCC	CCMIX (fall)	CCMIX (spring)	Least-square means
Biomass yield	pounds a^{-1}			
2016-2017	1360[‡]	5256 b[§]	1176[‡]	-
2017-2018	1617 d	3148 c	-[¶]	2382 B[#]
2018-2019	3263 c	6174 a	4920 b	5055 A
Least-square means	2471 B	4966 A		
C:N	C/N			
2016-2017	22 c	49 a	17 d	29 A
2017-2018	15 e	24 b	-[¶]	16 B
2018-2019	21 c	17 d	20 c	15 B
Least-square means	17 B	30 A	13 C	

[†] DSBCC: Double-crop soybeans plus a spring cover crop before sorghum planting, CCMIX: Cover crop mixture planted after wheat harvest and sampled in the fall and spring.

[‡] Include estimates of cover crop biomass yield from a nearby planting of the same species, managed in the same manner, and with no visual difference in productivity. Not included in analysis of variance.

[§] Interaction means followed by the same lower-case letter do not differ ($\alpha = 0.05$).

[¶] Not estimated because cover crop species did not survive the winter.

[#] Main-effect means followed by the same upper-case letter do not differ ($\alpha = 0.05$).

Table 2.5. Inorganic nitrogen in the soil to a depth of 24 in at sorghum planting after cover crop treatments in a no-till three-yr sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2017-2019.

Season N-rates‡	Cover crop treatment† CF	DSB	DSBCC	CCMIX	N-rate mean
	——————pounds acre^{-1} ——————				
2017					121a§
0	149	128	109	111	124
40	132	147	115	120	128
80	135	129	99	107	118
120	118	126	99	119	115
160	123	131	105	117	119
Trt. mean	132A	132A	106B	115BA	
2018					93b
0	104	100	62	108	94
40	110	99	65	93	92
80	104	116	64	90	94
120	105	120	66	92	96
160	108	96	69	96	92
Trt. mean	106A	106A	65B	96A	
2019					71c
0	76	86	64	62	72
40	72	85	64	60	70
80	75	85	64	61	71
120	73	87	60	60	70
160	69	84	64	68	71
Trt. mean	73B	86A	63C	62C	
Trt. mean Over yr	104A	108A	78C	91B	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.
‡Nitrogen rates: values indicate N applied as pounds acre^{-1}.
§Differences between year means followed by the same lowercase letter are not significant at $\alpha = 0.05$ and between main effect means within or over years followed by the same uppercase letter are not significant at $\alpha = 0.05$.

Chapter 3 - Grain sorghum response to cover crops and nitrogen fertilizer

Abstract

Soil fertility plays a crucial role in determining yield of sorghum, and adding cover crops that can help aid in soil fertility and reduce fertilizer requirements, would seem beneficial. Therefore, a study was conducted to i) evaluate how cover crops affect sorghum growth, development, and yield. The experiment was conducted in a randomized complete block design with four treatments: chemical fallow (CF), double-crop soybeans (DSB), double-crop soybeans plus a spring cover crop before sorghum (DSBCC), and a summer cover crop mixture after wheat (CCMIX). Nitrogen (N) rates consisting of 0, 40, 80, 120, and 160 pounds acre^{-1} were subsurface banded after sorghum planting. Canopeo, NDVI, and SPAD were gathered during the growing season to determine vegetative growth. Response variables consisting of half-bloom, heads plant^{-1}, head size, seed weight, and test weight were either captured during the growing season (half-bloom) or calculated later to characterize the development of sorghum. Fallow management treatments slowed vegetative growth of sorghum, but to a greater degree with DSBCC than CCMIX. Aside from seed weight and test weight, where cover crops increased these values, the other response variables were hindered by cover crops, but to a greater degree from DSBCC than CCMIX. The DSB treatment was not different from CF in all response variables aside from yield, when DSB had lower yields in 2018, but greater in 2019. Only in 2018, when adverse weather conditions were experienced, did a fallow-management alternative to CF hinder yield performance of the subsequent sorghum crop significantly when grain yield was reduced by more than 50% after DSBCC compared to CF.

Introduction

Sorghum is an important cereal crop found all over the globe and is comprised of five different races (Mundia et al., 2019). These races include bicolor, guinea, caudatum, kafir, and durra (Mundia et al., 2019). Of these five races, bicolor is predominately the race that dominates the market (Mundia et al., 2019), and was also the race used in this study. Sorghum has a unique set of properties that allow it to be grown in difficult climates, where other crops would fail. Typically, sorghum is grown in areas that experience hotter temperatures and lower precipitation events on a broad scale of soils (Mundia et al., 2019, Baligar and Fageria, 2007). While most crops favor a narrow pH range for optimal growth, sorghum can tolerate a range of pH from 5.0 to 8.5 (Baligar and Fageria, 2007). Though sorghum is drought tolerant, it is also better at handling water-logged soils compared to a similar crop such as corn, though its production is lower (Mundia et al., 2019, Baligar and Fageria, 2007). In a study conducted by Staggenborg et al. (2008), both grain sorghum and corn were compared at sites located in Kansas and Nebraska. Results proved that when weather conditions were favorable, both grain sorghum and corn yields increased. When adverse weather conditions were experienced, grain sorghum out performed corn, that was likely related to drought and temperature tolerance. Yield comparisons between corn and sorghum were assessed by Assefa et a. (2014). Multiple hybrids between corn and soghum were evaluated between multiple counties in Kansas. Average yields of dryland and irrigated corn, over seven decades (1939-2009), were 96 bushels acre^{-1} and 175 bushels acre^{-1}, respectively. Mean yields of dryland and irrigated sorghum, over five decades (1957-2008), were 86 bushels acre^{-1} and 137 bushels acre^{-1}, respectively. The authors also reported that changes in yield, over years, were due to management practices such as population, planting and harvesting dates, etc. as well as weather conditions.

Overall, sorghum is a very versatile crop and thrives in areas were other crops cannot; and depending on the region also determines the use of the crop. Primarily, the greatest percentage of sorghum production comes from Africa and Asia, accounting for more than 90% of the harvested area (Mundia et al., 2019). Looking further, within northern Africa, Nigeria and Sudan are the leading producers and typically, sorghum is used for porridge or alcoholic beverages. In Asia, India and China are the leading producers and sorghum is commonly used for bread, porridge, and alcoholic beverages. The primary use of sorghum in the US is for livestock feed, while the remaining portion is used for ethanol production (Mundia et al., 2019, Ciampitti and Prasad, 2019). With sorghum being used primarily for food products in Asia and Africa, the growth and development of sorghum are of great importance, and anything to impede its performance would probably not be accepted. However, sorghum has the ability of drought tolerance as well as functionality under higher temperatures. These abilities allow sorghum to be a viable option for crop rotations when abiotic stresses can prove challenging.

Crop rotation has been practiced since antiquity because of several benefits, it provides within the cropping system. Crop rotation is the practice of growing different crops in succession over a given time period (Reeves, 1994, Castellazzi et al., 2008). The sequence of crops depends on the growers' objectives, whether it be profitability or soil and environmental quality (Castellazzi et al., 2008). Crop rotations are not limited to cash crops, and additional cover such as cover crops can be implemented. Crop rotation, in accordance with either grain crops or cover crops, are utilized for the benefits they provide to the system. Such benefits include improved soil structure, water retention, and the addition of SOM. Besides soil improvements, crop rotations are great at eliminating pest problems. When different species are grown, pests (insects, weeds, and diseases) cycles are disrupted due to pests having narrow host ranges (Reeves, 1994).

Though crop rotations have numerous benefits cited from the literature, there are skeptics in the agricultural community that question the effectiveness of this practice. Many wonder about the impact that crop rotations will have on the yield potential and water availability for the subsequent crop. Given the benefits cited and skepticism amongst the community, further research is needed to help understand the truth. Our hypothesis was that intensifying a cropping system with double crops and cover crops would influence the subsequent grain crop. The objective of the research was to evaluate how increasing intensity with double crops and cover crops affects sorghum growth, development, and yield.

Materials and Methods

Grain Sorghum Management

Field trials were conducted from 2017 to 2019 within a long-term No-Till Wheat-Sorghum-Soybean Cover Crop rotation established in 2007 at the Kansas State University Department of Agronomy research farm located near Manhattan, KS (39.124037, -96.636469). The experimental design was a randomized complete block in a split-split plot arrangement with four replications. Crop phase (wheat, sorghum, or soybean) were the whole plots, cover crop treatments were the split plots, and nitrogen (N) rates of 0, 40, 80, 120, or 160 lb acre^{-1} applied to the sorghum phase were the split-split plots. Each cover crop plot was 20 ft by 200 ft, and subplots were 20 ft by 40 ft. Cover crop treatments included: Control-Chemical fallow (CF), Double-crop soybeans (DSB), Double crop soybeans plus a spring cover crop planted in March and terminated before sorghum planting (DSBCC), and a cover crop mixture planted after wheat harvest and terminated by either freezing temperatures or with herbicide application before sorghum planting (CCMIX). All weather data, presented in figures, was accessed from a weather station located approximately 800 ft from the center of the experiment (Kansas Mesonet, 2020).

Grain Sorghum was planted in May or June of the 2017, 2018, and 2019 seasons using a White 6200 4-row planter (AGCO-Corp. Duluth, GA). The hybrid was Pioneer 84G62 (2017-2018) and Pioneer 84P68 (2019) with a target seeding rate of 75,000 to 80,000 seeds $acre^{-1}$. Seeding depth was approximately 1.5 in with a row spacing of 30 in. Herbicides were applied at the time of planting in a volume of 15 gallons $acre^{-1}$ to burn down emerged weeds and provide residual control of weeds likely to germinate after sorghum emergence: 2017 – 4 pt/ac^{-1} Gramoxone and 2.4 qt/ac^{-1} Lumax EZ (Mesotrione, S-metolachlor, and atrazine) plus 2 pt 100 $gallon^{-1}$ NIS (non-ionic surfactant); 2018 – 4 pt ac^{-1} Gramoxone, 5.4 oz ac^{-1} Explorer, 28 oz ac^{-1} Brawl II, and 20 oz ac^{-1} Atrazine 4L, Lumax EZ (0.17 lb ac^{-1} Mesotrione, 1.67 lb ac^{-1} S-metalochlor, 0.63 lb ac^{-1} Atrazine) plus NIS; 2019 – 4 pt ac^{-1} Gramoxone, 64 oz $acre^{-1}$ Glyphosate, 6 oz $acre^{-1}$ Callisto, 20 oz ac^{-1} Atrazine 4L, and 28 oz ac^{-1} Brawl II plus NIS. In 2017, a post-emergence herbicide application of 16 oz of Huskie and 0.75 lb atrazine ac^{-1} plus AMS and NIS was made to control Palmer amaranth that was competing with the sorghum at growth state GS3 (growing point differentiation) (Roozeboom and Prasad, 2016). Nitrogen rates were applied within 10 days after planting in all years as subsurface banded UAN (28-0-0) using a straight flat coulter liquid fertilizer applicator.

Throughout the growing season, several types of data were collected to assess sorghum response to previous cover crop treatments. Normalized difference vegetation index (NDVI) was captured several times between growing point differentiation (GS3) and soft dough (GS7) using a Green Seeker® crop sensor (Trimble Navigation Ltd., Sunnyvale, CA) configured for manual data collection in research applications. Values were collected from entire length of single bordered row in each plot. Green Seeker® NDVI values were used to estimate in-season leaf N status and biomass production (Shaver et al., 2011) based on the relative reflectance of red (RED) and near infra-red (NIR) bands emitted by the instrument as follows: NDVI= (NIR-RED)/ (NIR+RED. Chlorophyll status was estimated (Süb et al., 2015) when sorghum had reached GS7 or GS8 using a SPAD meter (SPAD 502 DL Plus, Chlorophyll Meter, Spectrum Technologies, Inc. Aurora, IL). Values for each plot consisted of an average of SPAD values obtained from the first leaf below flag leaf from 20 plants in the same area as sampled for NDVI (Fontes et al., 2017). Canopeo (Oklahoma, 2015) was used to estimate percent canopy coverage throughout the growing season. Measurements were taken beginning at GS3 and continued until sorghum reached GS7/GS8 growth stage. Four values for % canopy cover were captured per plot, each encompassing an area of approximately 5 ft × 3 ft to include the center two rows, and were averaged to provide a single value for each plot. Plant counts for population estimates were conducted in each plot covering a 50 ft^2 area once plants had reached GS1. Plant heights and head counts were obtained when plants had reached full maturity (GS9). Head counts were assessed by counting all heads in the center two rows of each plot and adjusting to heads $acre^{-1}$.

Dry matter (DM) and N accumulation were assessed when grain sorghum reached full maturity (GS9). Plants were clipped at the soil surface from a uniform meter-length of row within a bordered row in each subplot. Panicles and stover were weighed separately. Stover was passed through a chipper shredder (model CS 3310, Cub Cadet, Valley City, OH), and a subsample was taken for determination of DM content. Both heads and stover were placed in a dryer at 60 °c until dry. Heads were threshed after drying using a stationary thresher (Model SPVT, ALMACO, Nevada, IA), and seed weight was captured. The mass of the panicle without the seed was added to the stover mass before calculating total stover yield. Total plant dry matter accumulation was estimated as the sum of panicle and stover weight, expressed per unit of area (lb acre^{-1}). Nitrogen accumulated in the grain, stover, and the two combined, were calculated using the following equations (Fontes et al., 2017).

Equation 3.1 $N\ accumulated\ in\ Stover\ (pounds\ acre^{-1}) = Stover\ yield\ \times \frac{Stover\ \%N}{100}$

Equation 3.2 $N\ accumulated\ in\ Grain\ (pounds\ acre^{-1}) = Grain\ yield\ \times \frac{Grain\ \%N}{100}$

Equation 3.3 $Total\ N\ uptake\ (pounds\ acre^{-1}) = Stover\ N + Grain\ N$

Dry grain samples were ground using a coffee grinder (model Rocky Doserless, Rancilio Group, Woolbridge, IL) to achieve powder-like consistency. Stover samples were ground using a Willey Mill (Thomas Scientific, Swedesboro, NJ), and a subsample of both grain and stover were analyzed for nitrogen concentration using the salicylic sulfuric acid digestion method (Bremmer and Mulvaney, 1982). Grain yield was estimated by harvesting the center two rows of each subplot with a modified 2-row Gleaner Model E-III combine (AGCO-Corp. Duluth, GA). Grain samples were passed through a grain analyzer computer (model GAC 2000, Dickey-John Corp., Springfield, IL) to estimate moisture content and test weight. Grain yield estimates were standardized to 12.5% moisture. Seed size was determined by weighing the mass of 300 seeds.

Results

The total precipitation for the 2017 (28.87 in) and 2018 (32.27 in) seasons were slightly below the Normal (32.55 in), while the 2019 season experienced higher than Normal precipitation (42.62 in) (Figure 3.1A). The months within each growing season varied in rainfall compared to the Normal. The 2017 season had events of higher than Normal precipitation for the months of March, April, August, and October. The 2018 season remained lower than Normal precipitation for a 7-month stretch (January through July) before exceeding the Normal precipitation for the months of August, September, and October. The 2019 season had large spikes for the months of May and August, while July was below Normal and the other months had Normal precipitation.

Temperatures for all three growing seasons showed less variation from the Normal compared to precipitation (Figure 3.1B). The 2017 season was warmer than Normal in January, February, and March, while the other months showed only slight deviations from Normal. The 2018 season showed the most variation with cooler temperatures in March, April, and September through November, and warmer than Normal temperatures in May and June. The 2019 season was cooler than Normal in January through March and again in September through October, while the month of August was warmer than Normal.

In-season Response

In-season response measurements consisted of percent canopy cover (2018-2019) and NDVI (2017-2019) recorded on multiple dates during vegetative growth, and SPAD values recorded at or soon after anthesis (2017-2019). Canopy cover values estimated using the Canopeo mobile telephone application were analyzed by date to determine the effect of cover crop treatments, nitrogen rates, and their interaction. The only significant cover crop×nitrogen interaction occurred at the last date in 2019 (Table 3.1). A cover crop effect was present at every date in 2018, but only the first two dates in 2019. Results highlighted that the DSBCC treatment had the lowest values compared to the rest of the treatments whenever there was a significant cover-crop treatment effect (Figure 3.2A). The CCMIX was significantly less than CF in 1 out of 8 dates in 2018 and in 2 dates in 2019. In 2019, both DSBCC and CCMIX had less canopy cover than CF and DSB but were not different from one another (Figure 3.2B). A nitrogen fertilizer rate effect was present at only two dates in both 2018 and 2019 (Table 3.1). In 2018, the 0 pounds acre^{-1} rate had the lowest % cover at the last two data collection dates in August (Figure

3.3A). In 2019, a nitrogen effect was observed in the middle of July and again in late July. The 0 pounds acre^{-1} N rate had the lowest values, however, it was not statistically different from 40 and 120 pounds acre^{-1} on 16-July and 120 pounds acre^{-1} on 30-July (Figure 3.3B).

The Normalized Difference Vegetative Index (NDVI) values were analyzed by date to determine the effect of cover crop treatments, nitrogen rates, and their interaction. There was no cover crop×nitrogen interaction observed at any date in any year (Table 3.1). There was a cover crop effect present at all dates for the 2017 and 2018 seasons, though cover crop effect was only present at the first two dates in 2019. Results proved that in 2017 DSBCC treatment had the lowest value at one date, while CCMIX had the lowest values at two dates (Figure 3.4A). In 2018, DSBCC had the lowest values at all dates compared to other treatments (Figure 3.4B). In 2019, both DSBCC and CCMIX treatments had the lowest values compared to CF and were not different from one another (Figure 3.4C). A nitrogen fertilizer effect was only present at 3 dates in 2017 and 2019 (Table 3.1). In 2017, the 0 pounds acre^{-1} rate had the lowest values at three out of four data collection dates (Figure 3.5A). There was no nitrogen fertilizer effect in 2018 (Table 3.1, Figure 3.5B). In 2019, the 0 pounds acre^{-1} rate had the lowest values; however, it was not statistically different from 40 pounds acre^{-1} on 16 and 30-July and 40 and 120 pounds acre^{-1} on 23-July (Figure 3.5C).

There was no year×cover crop×nitrogen interaction observed for any response variable. There was a year×nitrogen interaction for SPAD and Bloom, and a year×cover crop interaction for SPAD, Bloom, Height, Population, Heads per plant, and Head size. Results for these parameters are presented by year (Table 3.2).

SPAD measurements for the 2017 growing season was the only year were a cover crop×nitrogen interaction was significant (P= 0.004) when SPAD values for the DSBCC and

CCMIX treatments responded to N rate more than the CF and DSB treatments (Figure 3.6A). The highest recorded value was obtained in the CF treatment at the 120 pounds acre^{-1} N rate, while the lowest value was recorded in the DSBCC at the 0 pounds acre^{-1} N rate. Regardless of N rates, DSBCC treatment had the lowest overall values, though CCMIX was not different from DSBCC, but both were less than CF or DSB. There was a cover crop effect and nitrogen effect present in all three years. The 2017 season showed that CF and DSB were not different and DSBCC and CCMIX were not different, therefore CF and DSB were averaged and DSBCC and CCMIX were averaged. Fallow management treatments (DSBCC, CCMIX) represented a 7% reduction in SPAD values compared to CF and DSB (Figure 3.8A). In 2018, DSBCC was the only treatment that reduced SPAD values by roughly 12%, compared to CF, DSB, and CCMIX. The 2019 season resulted in a 3% (DSBCC) and 7% (CCMIX) reduction compared to CF, while DSB was not different from CF or DSBCC (Figure 3.8A). The nitrogen effect for both 2017 and 2019 proved that increasing N rates increased SPAD values. However, no increases were observed from 120 pounds acre^{-1} and on. N rates increased SPAD values in 2018, though no increases were dected from 40 to 160 pounds acre^{-1}.

Sorghum half-bloom date showed a cover crop×nitrogen interaction ($P= 0.006$). Sorghum half-bloom date was same after CF and DSB regardless of N rate applied. However, increasing N rates decreased days to half-bloom after DSBCC and CCMIX in 2017, but N rate had no effect on sorghum bloom date after CF and DSB (Figure 3.6B). Both DSBCC and CCMIX treatments were statistically different from CF, but not from each other. Both DSBCC and CCMIX treatments delayed half bloom the longest at the 0 N rate by roughly 4 days compared to DSB and by 6 days compared to CF. The shortest duration occurred in CF when both the 80 and 120 pounds acre^{-1} N rate reached half bloom roughly 66 days after planting. There was a cover crop effect present in all three years. In 2017 and 2019 both CF and DSB were not different and DSBCC and CCMIX were not different. The DSBCC and CCMIX treatments were responsible for delaying half-bloom of sorghum by roughly 4 days (2017) and 5 days (2019) compared to CF and DSB treatments. In 2018, DSBCC was the only treatment that delayed half-bloom of sorghum by roughly 11 days compared to CF, DSB, and CCMIX (Figure 3.8B). Both the 2017 and 2019 seasons, nitrogen effect played a role in reducing time to reach half-bloom. In 2017, all N rates, other than 0, reduced time to reach half-bloom by roughly a day. In 2019, again, N rates reduced days to half-bloom by roughly 2 to 3 days

Plant height of sorghum was not affected by cover crop×nitrogen interaction nor nitrogen in any year. There was however, a cover crop effect present for the 2018 season alone. Treatments consisting of CF, DSB, and CCMIX, when averaged (45 in), resulted in roughly a 9 in plant height advantage compared to DSBCC treatment (36.5).

The population of sorghum had a cover crop×nitrogen interaction (P= 0.016) for the 2019 season alone. Results indicated that the highest population was obtained after the DSB treatment at the 160 pounds acre^{-1} rate, while the lowest population occurred after CCMIX at the 80 pounds acre^{-1} rate. In both 2017 and 2019, sorghum population after CF and DSB were not different from each other and both DSBCC and CCMIX were not different from each other, but CF and DSB were statically different from DSBCC and CCMIX. Either DSBCC or CCMIX had the lowest populations in in all years. In 2017, CCMIX had the lowest population by 6110 plants acre^{-1}, and in 2018, DSBCC had the lowest population by 5804 plants acre^{-1} compared to CF and DSB. When averaged across years, CCMIX had the lowest population, resulting in a 4753 plants acre^{-1} deficit compared to CF and DSB. There was no nitrogen effect present in any year.

There was no cover crop×nitrogen interaction or nitrogen effect present in any year for heads plant^{-1}. There was a cover crop effect observed for the 2018 season. The CF, DSB, and CCMIX treatments were not statistically different and averaged together. Results showed that when averaged, there was roughly 1 head plant^{-1}, which is slightly greater compared to the DSBCC treatment (0.74 head plant^{-1}).

Head size did not have a significant cover crop×nitrogen interaction in either year. There was a cover crop effect (2018) and a nitrogen effect (2018, 2019) in the years head size was recorded. Cover crop effect, averaged across CF, DSB, and CCMIX, produced roughly 1947 seeds head^{-1}, but DSBCC treatment reduced head size by roughly 800 seeds head^{-1}. Nitrogen effect in 2018 showed that fertilizer rates, other than 0, increased head size, though no increase was observed from 40 up to 160 pounds acre^{-1}. Fertilizer rates (40-160 pounds acre^{-1}), when averaged, only increased head size by roughly 169 seeds head^{-1} comapred to the 0 N rate. The nitrogen effect in 2019 produced a different result. Head size increased with increasing N rates, though no increase was observed passed 80 pounds acre^{-1}. The increases observed were 131 seeds head^{-1} (0-40 pounds acre^{-1}) and 115 seeds head^{-1} (40-80 pounds acre^{-}).

Harvest Response

There was no year×cover crop×nitrogen interaction present for any response variable. There was however a year×nitrogen, year×cover crop, and a cover crop×nitrogen interaction present for yield, biomass, stover %N, and grain %N. There was also a year×nitrogen and cover crop×nitrogen interaction for N uptake, a year×cover crop and cover crop×nitrogen interaction for seed size, and a year×cover crop interaction for test weight (Table 3.2).

Yield response of sorghum, in 2017, had a cover crop×nitrogen interaction (P= <0.001) and proved that the lowest yields were obtained in the DSBCC treatment at the 0 pounds acre^{-1} N rate, while the highest yields were obtained from the CCMIX treatment at 80 pounds acre^{-1} (Figure 3.7A). There was a cover crop effect (2018, 2019) and a nitrogen effect (2017, 2019) present. In 2018, CF and CCMIX were not different, but were different from DSB and DSBCC. CF and DSB treatments produced the greatest yields (133 bushels acre^{-1}), while DSBCC treatment was responsible for reducing yields by roughly 71 bushels acre^{-1}. In 2019, the DSB treatment produced the greatest yields (117 bushels acre^{-1}), while CF, DSBCC, and CCMIX (112, 108, 110, respectively) were not different and had the lowet yields. Though the reduction experienced was less severe than in 2018 (Figure 3.9A). Yield increases were observed from increasing N rates in 2017, though no increases were observed after 80 pounds acre^{-1}. The 2019 nitrogen effect showed that yield increased with increasing N rates, with 0 pounds acre^{-1} having the lowest yield (99 bushels acre^{-1}) and 160 pounds acre^{-1} having the greatest (121 bushels acre^{-1}).

Seed size was captured for the 2018 and 2019 growing seasons and had no cover crop×nitrogen interaction present. In 2018, a cover crop effect was present and CF, DSB, and CCMIX were not statistically different, but were different from DSBCC treatment. The treatment that reduced yield, DSBCC, had larger seed (9 g 300 seed^{-1}) than the other three treatments, CF, DSB, and CCMIX); average of 8 g 300 seed^{-1}). The nitrogen effect observed in 2019 showed that increasing N rate increased seed weight. This increase progressed until 80 pounds acre^{-1}, from 80 pounds acre^{-1} and on, there was no additional increase

Grain test weight had no crop×nitrogen interaction observed for any year. There was a cover crop effect and nitrogen effect present for the 2017 season alone. Results highlighted that DSBCC and CCMIX treatments, produced 61 pounds bushel^{-1} compared to 60 pounds bushel^{-1} for CF and DSB. The nitrogen effect showed that 0 and 40 pounds acre^{-1} were not different and

80 through 160 pounds acre^{-1} were not different from each other. The lower N rates (0 and 40) produced slightly greater test weight (60.8 pounds bushel^{-1}) compared to 80-160 pounds acre^{-1} (60.5 pounds bushel^{-1}).

There was a cover crop×nitrogen interaction only for 2019 ($P = 0.035$) when sorghum biomass yields for the DSBCC and CCMIX responded to fertilizer rates more than CF and DSB (Table 3.3). Results showed that the highest biomass was obtained under the DSB treatment (17556 pounds acre^{-1}) at the 120 pounds acre^{-1} rate, while the lowest yields were obtained from the DSBCC treatment (12829 pounds acre^{-1}) at the 40 pounds acre^{-1} rate. Cover crop effect was present for every growing season and was found that the DSBCC treatment consistently had the lowest biomass compared to the other treatments. However, in 2019 DSBCC was not statistically different from CCMIX or CF treatments. A nitrogen effect was present for the 2017 growing season only and proved that the 120 and 160 pounds acre^{-1} rates had the highest biomass, while the 0 pounds acre^{-1} had the lowest.

Harvest index did not incur a cover crop ×nitrogen interaction nor a nitrogen effect for any year. The cover crop effect experienced in 2018 showed that CF and CCMIX were not statistically different and DSB and DSBCC were not statistically different. Harvest index of CF and CCMIX (40) was slightly greaterh than for DSB and DSBCC (38).

Nitrogen concentration was captured for the 2017-2019 growing seasons in both stover and grain of sorghum. In 2017, a cover crop×nitrogen interaction ($P = 0.026$) showed that the highest nitrogen concentrations in stover occurred after the CF and DSB treatments at the 160 pounds acre^{-1} rate (1.6%). The lowest concentrations occurred after the DSBCC and CCMIX (0.7%) treatments at the 0 pounds acre^{-1} rate. A cover crop effect was present for the 2017 and 2019 seasons. Results showed that both DSBCC and CCMIX treatments had the lowest concentrations compared to DSB and CF, though DSB was not different from DSBCC and CCMIX (2019). A nitrogen effect also occurred for the same two seasons. In both cases, the 0 pounds acre^{-1} rate had the lowest nitrogen concentration in 2017 and 2019 compared to the 160 pounds acre^{-1} in 2017 and 2019 which had the highest compared to others. The 0 pounds acre^{-1} rate was not different from the 40 pounds acre^{-1} rate (2019) and 160 pounds acre^{-1} rate was not different from 80 and 120 pounds acre^{-1} rates (2019). There was no cover crop×nitrogen interaction, cover crop and nitrogen effect present in 2018.

The same interactions that occurred for stover content also occurred for grain content. The DSB treatment had the highest nitrogen concentration in 2017 and 2018 at the 160 pounds acre^{-1} rate when a cover crop×nitrogen interaction occurred ($P= 0.003$). The lowest values occurred in the DSBCC and CCMIX treatments (2017), and DSB treatment (2018) ($P= 0.014$). A cover crop effect was present for the same years when CCMIX had the lowest values, though it was not different from DSBCC (2017) and DSB and CF (2018). The highest concentration was found in the DSB (2017) and DSBCC (2018) treatments, though they were not different from CF. A nitrogen effect was present in all three years and showed that the 0 pounds acre^{-1} rate produced the lowest N concentrations in the grain, though it was not different from the 40 (2018 and 2019) and 80 (2018) pounds acre^{-1} rates.

Nitrogen uptake was calculated for the 2017-2019 growing seasons. A cover crop×nitrogen interaction ($P= 0.035$) occurred for the 2018 season only. Results showed that the greatest nitrogen uptake was in the DSB treatment at the 160 pounds acre^{-1} rate, and the lowest was in the same treatment at the 0 pounds acre^{-1} rate (Figure 3.7B). In both 2017 and 2019, CF and DSB were not statistically different and DSBCC and CCMIX were not statistically different. Therefore, both pair of treatments in each year were averaged. The DSBCC and CCMIX treatments resulted in roughly 45 pounds acre^{-1} (2017) and 29 pounds acre^{-1} (2019) deficit compared to CF and DSB, respectively (Figure 3.9B). In 2017, increasing N rate increased N uptake, though no increase was noticed from 120 pounds acre^{-1} and on. The 2019 season showed that there was no difference between 0 and 40 pounds acre^{-1} and no difference amongst 80 through 160 pounds acre^{-1}. The higher N rates (80-160 pounds acre^{-1}), on average, proved to have the greatest N uptake by roughly 30 pounds acre^{-1} compared to the 0 and 40 pounds acre^{-1} N rate.

Discussion

Though there were differences between years and response variables, at least one source of variation affected all in-season responses for sorghum. Canopeo results indicated that the addition of a spring cover crop (DSBCC) before sorghum planting slowed canopy closure when weather conditions were inadequate to support vigorous growth (Figure 3.1). The 2018 season proved to be a challenging year with lower than Normal precipitation (January-July) (Figure 3.1), resulting in a 31% reduction in canopy closure at the beginning of the season (29-June) and a 7% reduction later in the season (14-August) when a spring cover crop was present before sorghum planting. Aside from spikes of greater than Normal precipitation (May and August) in 2019, weather was relatively normal, but cover crops before sorghum planting still slowed canopy closure. Greater canopy coverage was aided by increasing fertilizer rates in both 2018 and 2019. Canopy cover is a helpful indicator of crop performance (Shepherd et al. 2018) Both Chung et al. (2017) and Jauregui et al. (2019) found positive relationships between percent canopy cover and biomass yields of crops grown. Chung et al. (2017) grew four sorghum cultivars in a greenhouse (no artificial light). Measurements were taken using a Canon camera and taken every week once plants had three to four leaves emerged. Biomass was represented as percentages based of green pixels, using Canopeo with default parameters. Results showed that percent canopy cover was highly correlated with plant height, proving that Canopeo is related to biomass production (Chung et al. 2017). Jauregui et al. (2019) grew different forage winter crops consisting of: common oats, wheat, barley, bristle or black oats, and Italian ryegrass, at seeding rates of either 22 or 89 pounds $acre^{-1}$. Three images per plot were taken before harvest. Results highlighted that all species showed a linear relationship between biomass and percent canopy cover (R^2= .81).

Canopeo is an effective tool for measuring canopy development. However, there is another method for measuring canopy development called light interception that was tested by Shepherd et al. (2018). The authors assessed canopy closure of soybeans using pictures and videos using Canopeo and light interception. Readings were taken once every two weeks, once soybeans had reached V2 and continued until R5. A linear relationship was present between the two Canopeo methods and the light interception method. Though there was a linear relationship, results indicated that pictures rather than videos, represented more variablilty with canopy development and that the light interception method may have underestimated canopy in the beginning of the season. The light interception method also has limitations such as cost, time, and time at which values can be recorded as reported by the author. Based on the results and difficulties associated with light interception, the author recommends using Canopeo, due to ease and accuracy of this device.

Both NDVI and SPAD readings, which are related to chlorophyll content and/or biomass production, varied between years. The SPAD values reported by Fontes (2017) showed a cover crop×nitrogen interaction, which is in accordance to what our study reported. Furthermore, increase in N rate led to increases in SPAD values in all treatment, except for CF and double-crop soybeans (Fontes, 2017). Increases in SPAD values from increasing N rates were variable in cover crop treatments and years from our study. In addition, SPAD showed a linear relationship with grain yield and N uptake. The increase in SPAD values as nitrogen rate increased agrees with the work of Jung et al. (2016), when he and his team found greater values with their highest nitrogen rate of 267 pounds acre^{-1}. Though in our study there was not a statistical difference between the 120 and 160 pounds acre^{-1}, the 120 nitrogen rate had the greatest SPAD values. Though maximum values differed between Jung et al. (2016) (46.3) at the 267 pounds N acre^{-1} and our study (59.1) at 120 pounds N acre^{-1}, it still shows a positive correlation between nitrogen rate and photosynthetic capability.

The previous work done on this study conducted by Fontes (2017), recorded NDVI values at growth stage 3 (growing point differenation) and again at growth stage 5 (boot). Differences occurred between Fontes's study of recording NDVI at two growth stages and assessment of individual crops on sorghum NDVI values. Comapred to this study of recording NDVI values from GS1 (three-leaf stage) to roughly GS5 and assessment of cover crop treatments as a whole, rather than individually. NDVI values were reduced at GS3 and GS5 for sorghum grown after sorghum-sudan (Fontes, 2017). Though our study did not evaluate individual cover crops, sorghum-sudan was apart of the CCMIX and NDVI values after CCMIX were reduced in 2017 and 2019. Furthermore, Fontes (2017) reported a linear relationship between NDVI and grain yield, and NDVI and N uptake. Just as increased SPAD values occurred with increased nitrogen rates, NDVI followed a similar trend and also was found by Sultana et al. (2018). The highest nitrogen rate in their study, 195 pounds acre^{-1}, had the highest NDVI values, and the lowest nitrogen rate, 0 pounds acre^{-1} , had the lowest NDVI values. Both

Jiang et al. (2003) and Goodwin et al. (2018) documented a positive relationship between NDVI values and grain yields in wheat. Half bloom of sorghum showed a negative relationship between nitrogen rates and time to reach half bloom, as was also found by Gordan and Whitney (1995). Gordan and Whitney (1995) experimented with 0, 10, 30, and 90 pounds acre^{-1} of nitrogen coupled with or without 30 pound acre^{-1} of P2O5. Fertilizer rates consisting of 30 pounds acre^{-1} of nitrogen: 30 pounds acre^{-1} of P2O5 and 90 pounds acre^{-1} of nitrogen: 30 pounds acre^{-1} of P2O5, when compared to the 0 nitrogen rate, reduced time form emergence to half bloom by roughly 7 days. Delaying of bloom date is of great importance given the potential for reducing the grain fill period. If bloom date is delayed, reductions of seed weight and yield can occur as a result of freezing temperatures (Shroyer et al., 1987; Staggenborg et al., 2008; Staggenborg and Vanderlip, 1996).

The plant stand of any crop is dependent upon abiotic factors such as water and temperature (Ciampitti and Prasad, 2019) to facilitate germination. If less than favorable temperature, moisture, or both occur, germination can be greatly reduced, affecting plant population. The 2017 and 2019 seasons experienced 4,000 to 6,000 fewer plants acre^{-1} after the DSBCC and CCMIX treatments compared to CF and DSB (Table 3.11). Weather conditions for the 2017 season had lower than Normal precipitation in May-July, and September and soil temperatures cooler than the optimal range of 64 to 69 ˚F (Ciampitti and Prasad, 2019). The lack of moisture coupled with cooler soil temps at the time of planting (Kansas Mesonet, 2020), is most likely the cause of the population deficit in 2017. The 2019 season experienced lower than Normal precipitation in June and July, though soil temperatures were either equal to or greater than the optimal range. Given this information, the population deficit experienced in 2019 was likely due to lack of moisture at the time of planting, germination, and emergence.

Both the height and number of heads per plant of sorghum displayed a similar response to the evaluated treatments. The height of sorghum remained unaffected by cover crop treatment or nitrogen fertilizer aside from the 2018 season. These findings disagree with the works done by Moghimi and Emam (2015), Jung et al. (2016), and Sher et al. (2016), who all found increases in height with increased fertilizer rates. Though there were differences between nitrogen rates and management practices, the highest nitrogen rates of 106 (Sher et al., 2016), 182 (Moghimi and Emam, 2015), and 267 (Jung et al., 2016) pounds acre^{-1} produced the tallest plants. Weather conditions coupled with the presence of cover crops affected sorghum height. The DSBCC treatment was responsible for stunting the height of sorghum by roughly 9 inches compared to the control. The number of sorghum heads per plant were affected in 2018 after the DSBCC treatment. The DSBCC treatment was responsible for a 23 to 30% reduction in heads produced.

The test weight of sorghum was affected by cover crop treatment and fertilizer rates only in 2017. Despite DSBCC and CCMIX treatments having negative impacts on the response variables mentioned above, both treatments lead to greater test weight than the control. Though statistically separated, the difference was only between 0.5 and 0.8 pounds bushel^{-1}. Though no head size or seed size was recorded for 2017, the heads per plant were reduced (no statistical difference). Based on this information, it is likely that test weight increased due to better allocation of resources. Fertilizer rate showed greater test weight with lower rates (0 and 40 pounds acre^{-1}) than higher rates (80, 120, and 160 pounds acre^{-1}). Again, though statistically different, they were separated by only 0.2 and 0.3 pounds bushel^{-1}. These findings disagree with work by Kaye et al. (2007), who found increases in test weight with greater nutrient amendments, either in the form of manure or nitrogen fertilizer.

The yield response of sorghum was drastically affected in 2018 by the DSBCC treatment, reducing yields by nearly half. However, in 2019, yields after the DSBCC, CCMIX, and CF were not different from one another, while sorghum after DSB had the highest yields. These findings disagree with Sindelar et al. (2006) and Blanco-Canqui et al. (2012) who reported increases from either cover crop use or crop rotations. Sindelar et al. (2006) grew either continuous crops (corn, grain sorghum, and soybean) or cover crops (oats and clover) in between rotations of corn, grain sorghum, and soybeans. Blanco-Canqui et al. (2012) grew cover crops (hairy vetch, sunn hemp, and late-maturing soybeans) after wheat in a winter wheat and grain sorghum rotation. Both studies showed similarities to our winter wheat-cover crop-grain sorghum rotation, the differences were corn instead of wheat (Sindelar et al., 2016) and the number of species, three (legume, grass, and brassica) after CCMIX and two (Legume and Grass) after DSBCC grown before sorghum. In both studies, either oats and clover were grown or individually of hairy vetch, sunn hemp, and soybeans, whereas our study grew either three species (DSBCC) or seven to eight species (CCMIX) before sorghum planting. Biomass accumulation from cover crop growth could have been the reason as to why there were yield deficits observed in our study. Restovich et al., (2012) reported that cover crops that had the greatest biomass or close to the greatest biomass, typically reduced the yields of corn. In both 2017 and 2019, yields increased with increasing fertilizer rates. Increased yields from fertilizer rates have been recorded by Sindelar et al. (2016) and Abunyewa et al., (2017). Though there were variations between crop rotations, nitrogen rates, and management practices, all studies showed yield increases with increased nitrogen rates. Furthermore, Sindelar et al. (2016) found that the rotation consisting of corn-soybean-grain sorghum-oat/clover without fertilizer produced greater sorghum yield than continuous sorghum at 80 pounds acre^{-1} of nitrogen and greater than corn-oat/clover-grain sorghum-soybean rotation at 160 pounds acre^{-1} of nitrogen. Previous work on this study conducted by Fontes (2017) found that 120 pounds acre^{-1} produced the greatest yields, except for sorghum-sudan and double-crop soybeans; and when not fertilizer was applied, late-matruing and double-crop soybeans had the greatest yields. These findings disagree with what our study found, yields obtained from this study were variable amongst N rates in cover crop treatments and across years.

Head size and seed size produced opposite results for the DSBCC treatment in 2018. Head size after the DSBCC treatment in 2018 was reduced by 41% compared to CF, though differences occurred between reduced head size, reductions in head size due to water limitations were also found by Inuyama et al., (1976). The authors grew grain sorghum under water deficits at different stages of the sorghum life cycle and reported that water stress early on and before heading, reduced the head size of the sorghum plant. As a result of reduced head size, seed size was greatest after DSBCC treatment by 0.6 to 1.0 grams. This result is likely due to the fact that smaller heads produce less seed and the plant can focus more resources to each seed during grain fill. Though head size was reduced from DSBCC treatment, our study showed that seed size was greatest after DSBCC by 0.6 to 1.0 grams, despite growth and development setbacks. There was a positive relationship between seed size, head size, and fertilizer rate when a nitrogen effect was present. Increased seed size from the use of fertilizer and cover crops were also found by Kaufman et al. (2013) and Gerbremaria and Assefa (2015). The authors found increased seed size with the use of intermediate nitrogen rates consistent of 29 pounds acre^{-1} and 58 pounds acre^{-1} compared to either 0 or 89 pounds acre^{-1} (Kaufman et al., 2013), whereas with our study, seed size increased as nitrogen rates increased. Increased head size with increased fertilizer use was also found by Gebremaria and Assefa (2015). In their study, the highest nitrogen rate of 133 pounds acre^{-1} produced the greatest head size as was the case for our study. Though head sizes differed between nitrogen rates, all were greater than the control of 0 pounds acre^{-1} as reported by Gebremaria and Assefa (2015).

The biomass production of sorghum was greatly reduced after the DSBCC treatment in all years by 746 to 4,818 pounds acre^{-1} (Table 3.3). In 2017, a positive correlation existed between biomass accumulation and increasing fertilizer rates. These findings of increased biomass with increased nitrogen rates are supported by Hao et al. (2014) and Sher et al. (2016). Hao et al. (2014) evaluated the response of photoperiod-sensitive sorghum to nitrogen rates ranging from 0 to 306 pounds acre^{-1}. Biomass yield increased by 16 and 36 pounsd acre^{-1} for every two pounds of nitrogen input. Though nitrogen rates tested by Sher et al. (2016) were significantly less than Hao et al. (2014), a positive correlation still existed between increased nitrogen rates and higher biomass accumulation. According to Ciampitti and Prasad (2019) harvest index is roughly 50% when half bloom is reached, as long as grain fill is not under stress. Therefore, all of our numbers are under 50% and could be related to abiotic stresses like weather. Aside from 2018, harvest index was not affected by any source of variation. In 2018, DSBCC and DSB treatments proved to have the lowest harvest index. Previous work done on this studied showed that biomass accumulation in all cover crop treatments and double-crop soybeans, except sorghum-sudan, had the greatest accumulation at the highest N rate (160 pounds $^{-1}$) (Fontes, 2017). However, the greatest biomass accumulation was variable and did not always occur at 160 pounds acre^{-1} from our study.

Nitrogen uptake of the sorghum crop was affected by cover crop treatments and nitrogen rates in every season. In every year, both DSBCC and CCMIX had the least nitrogen uptake, ranging from 20 to 50 pounds acre^{-1} less than CF and DSB. This disagrees with the work done previously form this study by Fontes (2017), when some cover crops lead to an increase of N uptake. There was positive relationship between nitrogen uptake and fertilizer rates in all years. This positive relationship was also found in studies reported by Holman et al. (2019), Beyaert and Roy (2005), and Maw et al. (2017). Holman and his team found increases in N uptake from 46 pounds acre^{-1} at the 0 nitrogen rate, up to 90 pounds acre^{-1} at the 100 pounds acre^{-1} rate. Beyaert and Roy (2005) found that, though there were differences between forage sorghum-sudangrass cuttings and nitrogen accumulation, on average, nitrogen accumulation increased with nitrogen rates, reaching a maximum of 143 pounds acre^{-1} at a nitrogen rate of 174 pounds acre^{-1}. Similar to our study, Maw et al. (2017) tested five nitrogen rates consisting of 0, 49, 99, 149, and 199 pounds acre^{-1} and reported that the two highest nitrogen rates had the greatest nitrogen accumulation. The lower two nitrogen rates still lead to increases compared to the 0 nitrogen rate.

Nitrogen concentration was affected by cover crop treatment for both stover (2017 and 2019) and grain (2017 and 2018). There was a 23% reduction in stover nitrogen concentration after DSBCC and CCMIX treatments in 2017 and a 16% reduction in nitrogen concentration after DSBCC and CCMIX in 2019 compared to CF. Grain nitrogen concentration showed a 6% reduction after DSBCC and CCMIX in 2017 compared to CF. In 2018, DSBCC treatment had the greatest nitrogen concentration compared to others. Nitrogen effect was present in all years, except for stover in 2018. Increasing fertilizer rate showed a 42, 21, and 6% increase in grain nitrogen concentration for the 2017, 2018, and 2019 seasons respectively. Furthermore, stover nitrogen concentration increased by 75 and 20% in 2017 and 2019 respectively. Though numbers are not exact, these findings agree with Abunyewa et al. (2017). Abunyewa et al. (2017) studied the effects of nitrogen rates (0 and 133 pounds acre^{-1}) on nitrogen use efficiency. In both years of the experiment, stover nitrogen concentration increased by 18% (2006) and grain nitrogen concentration increased by 12% (2007) with the greater nitrogen fertilizer rate.

Conclusion

Intensifying and diversifying the cropping system significantly affected vegetative growth of sorghum. When averaged across dates for canopy and NDVI values, canopy closure was reduced by 29.7% and 33.9% after the DSBCC treatment in 2018 and 2019 respectively. CCMIX reduced canopy cover by 32% in 2019 alone. NDVI values were reduced after CCMIX by 9.7% (2017) and 20.8% (2019) and after DSBCC by 9% (2018) and 21.5% (2019). SPAD values were not averaged over dates because they were recorded only once during the season. Values decreased by 8, 13.5, and 5% in 2017, 2018, and 2019 after DSBCC, respectively. CCMIX reduced SPAD values by 5.7 and 6.7% in 2017 and 2019. The height of sorghum was affected only in 2018 when DSBCC reduced height by roughly 9 inches compared to all other treatments, likely due to reductions in soil moisture. The biomass production was reduced after DSBCC by 9.4 (2017), 27 (2018), and 5% (2019). CCMIX reduced biomass production by 5.8% in 2019 alone. The half bloom of sorghum was delayed after DSBCC by roughly 3 (2017), 11 (2018), and 5 days (2019) and after CCMIX by roughly 3 (2017) and 5 days (2019). Vegetative growth was reduced with the incorporation of cover crop treatments and was accelerated under adverse weather conditions.

The development of sorghum, including yield components such as heads per plant, head size, and seed size, also were affected by cover crop intensity and diversity. Heads per plant and head size suffered the most from DSBCC treatment, resulting in a 29% reduction in the number of heads plant^{-1} and 41% reduction in head size in 2018. There was a 5.8% decrease in heads plant^{-1} after CCMIX in 2018. Both seed size and test weight were increased after DSBCC by 8.2% (2018) and 1.3% (2017) respectively, likely reflecting compensation for the reduced seed number in this treatment. In 2017, CCMIX increased test weight by 1.2% compared to CF. The positive response of seed size and test weight to cover crop use was likely a compensation for the reductions in other yield compoentents resulting from the incorporation of cover crops.

Yield of sorghum, which is dependent upon yield components mentioned above, was affected in the 2018 and 2019 seasons. The 2018 season suffered lower than Normal precipitation for the winter, spring, and part of summer months, resulting in a 54.5% decrease in yield after DSBCC treatment. This is most likely the result of having an actively growing cover crop directly before sorghum planting, whereas cover crops from CCMIX had very little or no growth before sorghum planting. The 2019 season only experienced a 3 and 1.3% decrease in yield from DSBCC and CCMIX, respectively. Overall, the incorporation of cover crop treatments reduced vegetative growth, heads per plant, head size, half bloom, and N uptake of sorghum. As a result, the yields of sorghum suffered from cover crop use in this cropping system. Therefore, we reject the oringal hypothesis of increasing intensity between fallow period would increase N during sorghum phase and positively influence sorghum growth, development, and yield.

References

Abunyewa, A.A., R.B. Ferguson, C.S. Wortmann, and S.C. Mason. 2017. Grain sorghum nitrogen use as affected by planting practice and nitrogen rate. J. Soil Sci. Plant Nutr. 17(1):155-166. doi:10.4067/s0718-95162017005000012

Assefa, Y., K. Roozeboom, C. Thompson, A. Schlegel, L. Stone, and J.E. Lingenfelser. 2014. Corn and grain sorghum comparison: all things considered. Elsevier, Amsterdam.

Baligar, V.C., and N.K. Fageria. 2007. Agronomy and physiology of tropical cover crops. J. Plant Nutr. 30(8):1287–1339. doi:10.1080/01904160701554997

Beyaert, R.P., and R.C. Roy. 2005. Influence of nitrogen fertilization on multi-cut forage sorghum-sudangrass yield and nitrogen use. Agron. J. 97(6):1493–1501. doi:10.2134/agronj2005.0079

Blanco-Canqui, H., M.M. Claassen and D.R. Presley. 2012. Summer cover crops fix nitrogen, increase crop yield, and improve soil–crop relationships. Agron. J. 104:137-147.

Bremmer, J.M. and C.S. Mulvaney. 1982. Salicylic acid thiosulfate modification of the kjeldhal method to include nitrate and nitrite. p. 621. In R.H. Miller and D.R. Keeney (eds.) Methods of soil analysis: Part 2. American Society of Agronomy, Madison, WI.

Castellazzi, M., G. Wood, P. Burgess, J. Morris, K. Conrad, and J. Perry. 2008. A systematic representation of crop rotations. Agric. Syst. 97(1-2):26–33. doi:10.1016/j.agsy.2007.10.006

Chung, Y.S., S.C. Choi, R.R. Silva, J.W. Kang, J.H. Eom, and C. Kim. 2017. Case study: Estimation of sorghum biomass using digital image analysis with Canopeo. Biomass and Bioenergy 105:207–210. doi:10.1016/j.biombioe.2017.06.027

Ciampitti, I.A., and P.V.V. Prasad. 2019. Sorghum: a state of the art and future perspetives. American Society of Agronomy, Madison, WI.

Fontes, G. 2017. Managing cover crops and nitrogen fertilizer to enhance sustainability of sorghum cropping systems in Eastern Kansas. M.S. Thesis. Kansas State University, Manhattan.

Fontes, G.P., P.J. Tomlinson, K.L. Roozeboom, and D.A.R. Diaz. 2017. Grain Sorghum Response to Nitrogen Fertilizer following Cover Crops. Agronomy Journal 109(6): 2723–2737. doi:10.2134/agronj2017.03.0180

Gebremaria, G., and D. Assefa. 2015. Nitrogen fertilization effect on grain sorghum (*Sorghum bicolor* L. Moench) yield, yield components and witchweed (*Striga hermonthica* (Del.) Benth) Infestation in Northern Ethiopia. International Journal of Agricultural Research 10(1):14–23. doi:10.3923/ijar.2015.14.23

Goodwin, A.W., L.E. Lindsey, S.K. Harrison, and P.A. Paul. 2018. Estimating wheat yield with normalized difference vegetation index and fractional green canopy cover. Crop, Forage & Turfgrass Management 4(1):180026. doi:10.2134/cftm2018.04.0026

Gordon, W.B., and D.A. Whitney. 1995. No-Tillage Grain Sorghum Response to Starter Nitrogen-Phosphorus Combinations. jpa 8(3):369. doi:10.2134/jpa1995.0369

Hao, B., Q. Xue, B.W. Bean, W.L. Rooney, and J.D. Becker. 2014. Biomass production, water and nitrogen use efficiency in photoperiod-sensitive sorghum in the Texas High Plains. Biomass and Bioenergy 62:108–116. doi:10.1016/j.biombioe.2014.01.008

Holman, J.D., A.K. Obour, and D.B. Mengel. 2019. Nitrogen application effects on forage sorghum production and nitrate concentration. J. Plant Nutr. 42(20):2794–2804. doi:10.1080/01904167.2019.1659321

Inuyama, S., J.T. Musick, and D.A. Dusek. 1976. Effect of Plant water deficits at various growth stages on growth, grain yield and leaf water potential of irrigated grain sorghum. Japanese journal of crop science 45(2):298–307. doi:10.1626/jcs.45.298

Jáuregui, J.M., F.G. Delbino, M.I.B. Bonvini, and G. Berhongaray. 2019. Determining yield of forage crops using the Canopeo mobile phone app. Journal of New Zealand Grasslands 81:41–46. doi:10.33584/jnzg.2019.81.385

xJiang, D., N.-B. Wang, X.-H. Yang, and J.-H. Wang. 2003. Study on the interaction between NDVI profile and the growing status of crops. Chinese Geographical Science 13(1):62–65. doi:10.1007/s11769-003-0086-4

Jung, J.S., Y.-J. Kim, W.H. Kim, S.-H. Lee, H.S. Park, K.C. Choi, K.-W. Lee, T.-Y. Hwang, and G.-J. Choi. 2016. Effect of nitrogen fertilization levels and its split application of nitrogen on growth characters and productivity in sorghum × sudangrass hybrids [*Sorghum bicolor* (L.) Moench]. Journal of The Korean Society of Grassland and Forage Science 36(3):215–222. doi:10.5333/kgfs.2016.36.3.215

Kaufman, R.C., J.D. Wilson, S.R. Bean, D.R. Presley, H. Blanco-Canqui, and M. Mikha. 2013. Effect of Nitrogen Fertilization and Cover Cropping Systems on Sorghum Grain Characteristics. Journal of Agricultural and Food Chemistry 61(24):5715–5719. doi:10.1021/jf401179n

Kaye, N.M., S.C. Mason, D.S. Jackson, and T.D. Galusha. 2007. Crop rotation and soil amendment alters sorghum grain quality. Crop Science 47(2):722. doi:10.2135/cropsci2006.05.0346

Kansas Mesonet. 2020. Weather Data Library. Kansas State University Agricultural Experiment Station. Manhattan, KS. Online: http://mesonet.k-state.edu/weather/historical/ (verified April 30, 2020)

Maw, M.J.W., J.H. Houx, and F.B. Fritschi. 2017. Nitrogen use efficiency and yield response of high biomass sorghum in the lower midwest. Agron. J. 109(1):115–121. doi:10.2134/agronj2016.01.0044

Moghimi, N., and Emam, Y. 2015. Growth and yield responses of two forage sorghum cultivars to different nitrogen fertilizer rates. Iran Agricultural Research 34(1):39-45.

Mundia, C.W., S. Secchi, K. Akamani, and G. Wang. 2019. A regional comparison of factors affecting global sorghum production: The case of North America, Asia and Africa's Sahel. Sustainability 11(7):2135. doi:10.3390/su11072135

Oklahoma State University. 2015. Canopeo. App StoreAvailable at https://apps.apple.com/us/app/canopeo/id929640529

Reeves, D.W. 1994. Cover crops and rotations. p. 125-172. In J.L. Hartfield and B.A. Stewart (eds.) Advances in soil science - crop residue management. Lewis Publishers, CRC Press, Boca Raton, FL, USA.

Restovich, S.B., A.E. Andriulo, and S.I. Portela. 2012. Introduction of cover crops in a maize–soybean rotation of the Humid Pampas: Effect on nitrogen and water dynamics. Field Crops Research 128: 62–70. doi:10.1016/j.fcr.2011.12.012

Roozeboom, K., and P.V.V. Prasad. 2016. Sorghum growth and development. in Sorghum:State of the Art and Future Perspectives, I. Ciampitti, V. Prasad, ed. ASA Monograph 58. ASA and CSSA, Madison, WI. doi:10.2134/agronmonogr58.2014.0062.

Shaver, T.M., G.A. Peterson, L.R. Ahuja, D.G. Westfall, L.A. Sherrod, and G. Dunn. 2002. Surface soil physical properties after twelve years of dryland no-till management. Soil Sci. Soc. Am. J. 66(4):1296–1303. doi:10.2136/sssaj2002.1296

Shepherd, M.J., L.E. Lindsey, and A.J. Lindsey. 2018. Soybean canopy cover measured with canopeo compared with light interception. Agric. Environ. Lett. 3(1):180031. doi:10.2134/ael2018.06.0031

Sher, A., F.-U. Hassan, H. Ali, and W. Hassan. 2016. Seed rate and nitrogen application effects on production and brix value of forage sorghum cultivars. Grassland Sci. 62(2):119–127. doi:10.1111/grs.12118

Shroyer, J., R.L. Vanderlip, D.L. Bark, J.A. Schaffer, and T.L. Walter. 1987. Probability of sorghum maturing before a freeze. AF-162. Kansas State University Cooperative Extension Service. Manhattan, KS.

Sindelar, A.J., M.R. Schmer, V.L. Jin, B.J. Wienhold, and G.E. Varvel. 2016. Crop rotation affects corn, grain sorghum, and soybean yields and nitrogen recovery. Agron. J. 108(4):1592. doi:10.2134/agronj2016.01.0005

Staggenborg, S.A., K.C. Dhuyvetter, and W.B. Gordon. 2008. Grain sorghum and corn comparisons: Yield, economic, and environmental responses. Agron. J. 100(6):1600–1604. doi:10.2134/agronj2008.0129

Staggenborg, S.A., and R.L. Vanderlip. 1996. Sorghum grain yield reductions caused by duration and timing of freezing temperatures. Agron. J. 88:473-477.

Süß, A., Danner, M., Obster, C., Locherer, M., Hank, T., Richter, K. 2015. Measuring leaf chlorophyll content with the Konica Minolta SPAD-502Plus- theory, measurement, problems, interpretation. EnMAP Field Guides Technical Report, GFZ Data Services. doi:http://doi.org/10.2312/enmap.2015.010

Sultana, S.R., A. Ali, A. Ahmad, M. Mubeen, M. Zia-Ul-Haq, S. Ahmad, S. Ercisli, and H.Z.E. Jaafar. 2014. Normalized difference vegetation index as a tool for wheat yield estimation: A case study from Faisalabad, Pakistan. The Scientific World Journal 2014:1–8. doi:10.1155/2014/725326

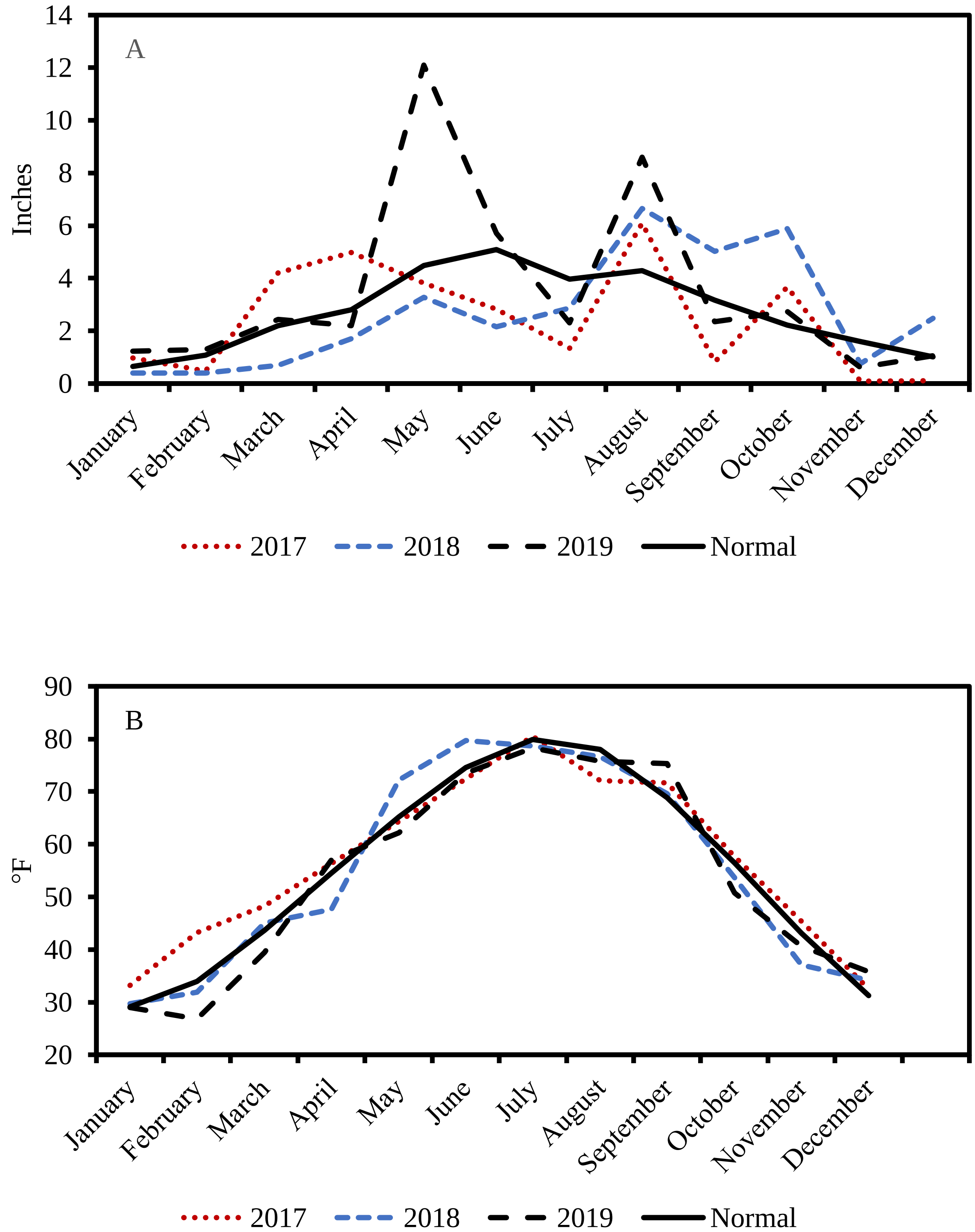


Figure 3.1. Precipitation events (A) and temperatures (B), separated by month and year, during sorghum growth and development at Manhattan, KS 2017 to 2019.

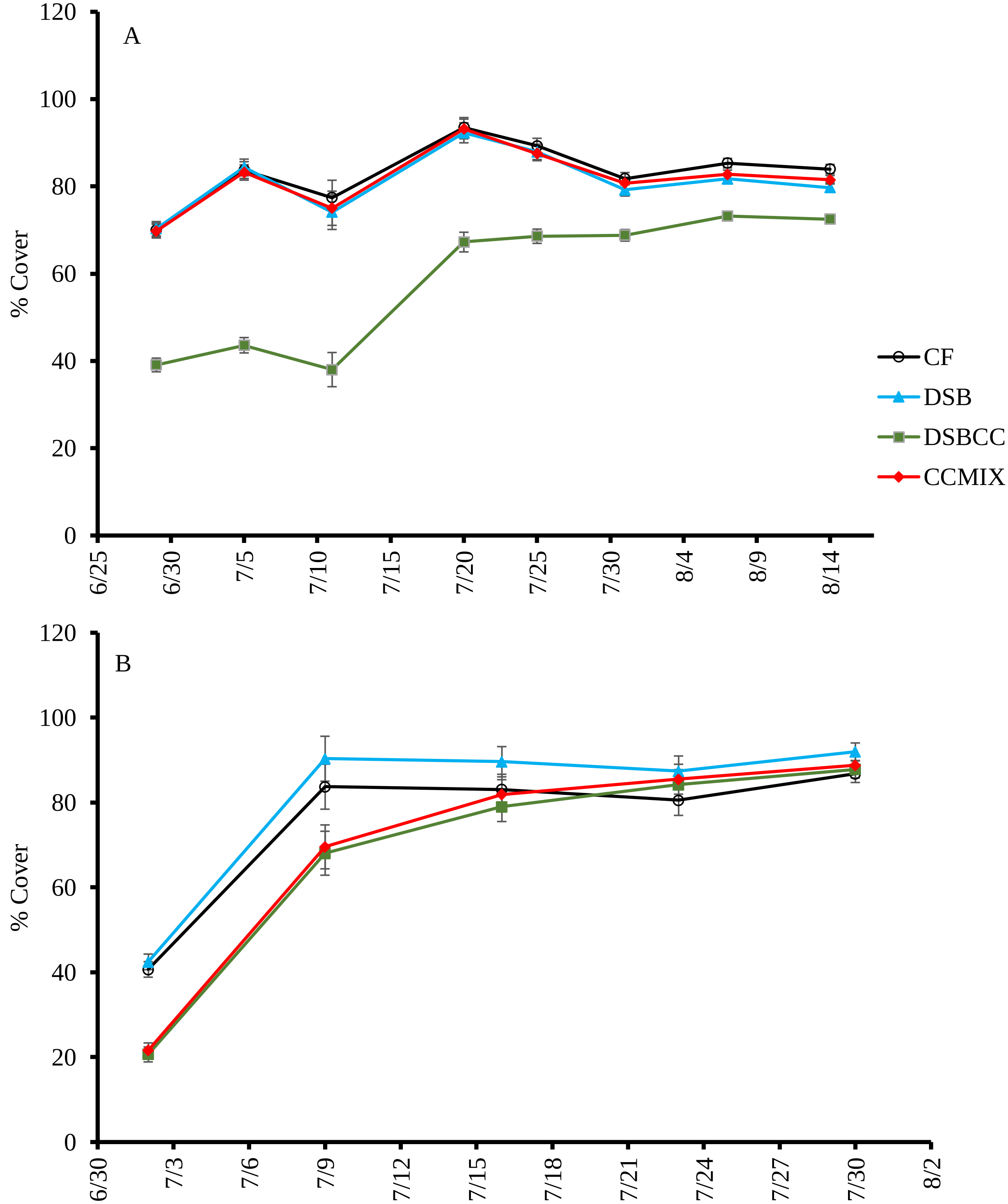
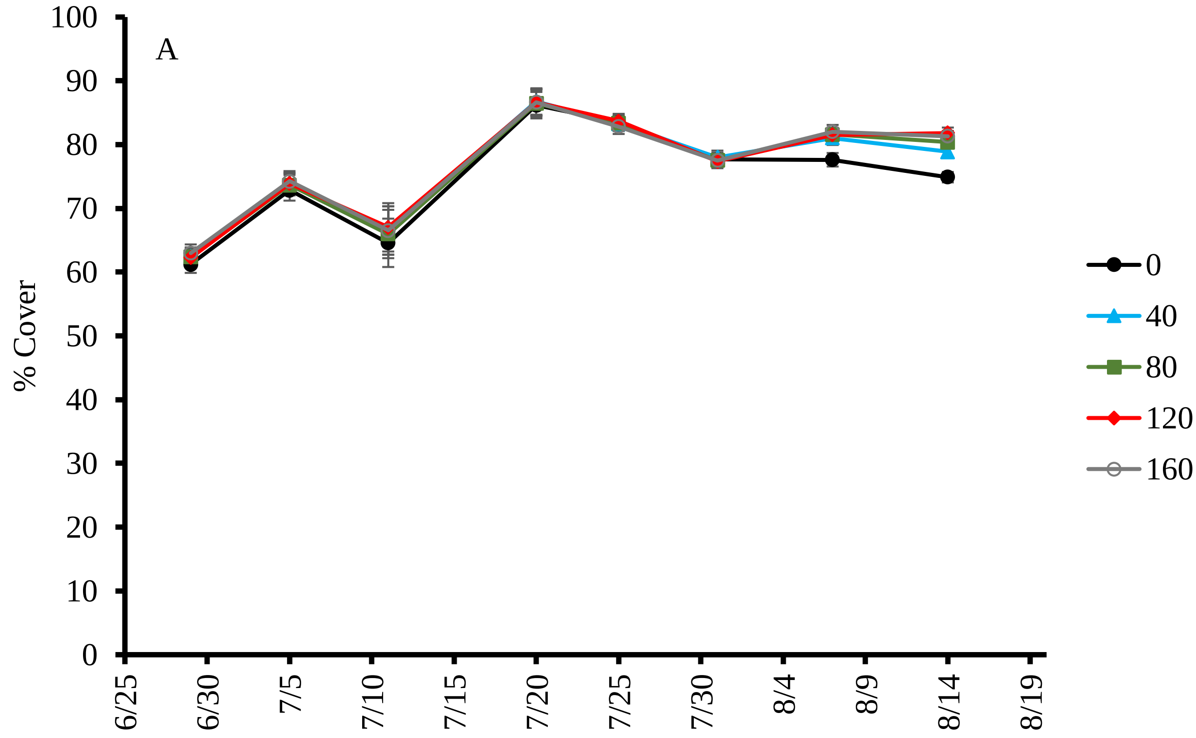


Figure 3.2. Cover crop effect on canopy cover in 2018 (A) and 2019 (B) during sorghum growth and development at Manhattan, KS 2018 to 2019. Treatments: chemical fallow (CF), double-crop soybean (DSB), double-crop soybean plus spring cover crop (DSBCC), summer cover crop mixture after wheat (CCMIX).



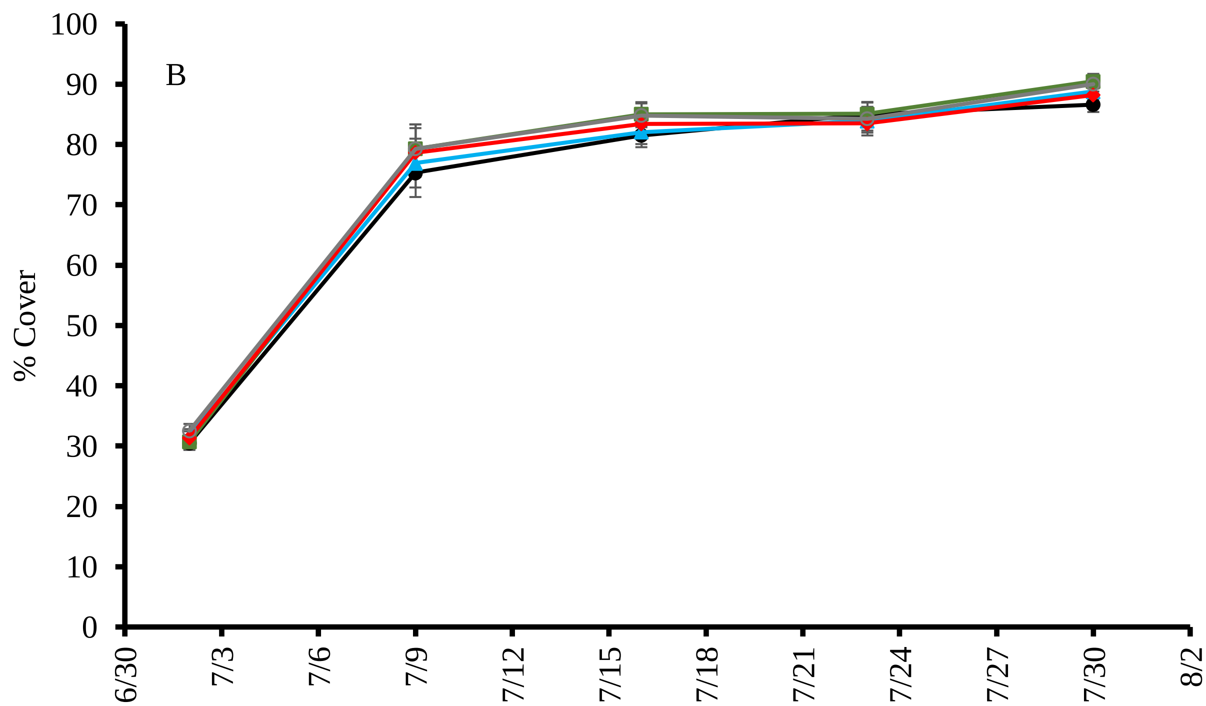


Figure 3.3. Nitrogen fertilizer application rate effect on canopy cover in 2018 (A) and 2019 (B) during sorghum growth and development at Manhattan, KS 2018 to 2019. 0, 40, 80, 120, 160 pounds acre^{-1} of N fertilizer applied at sorghum planting.

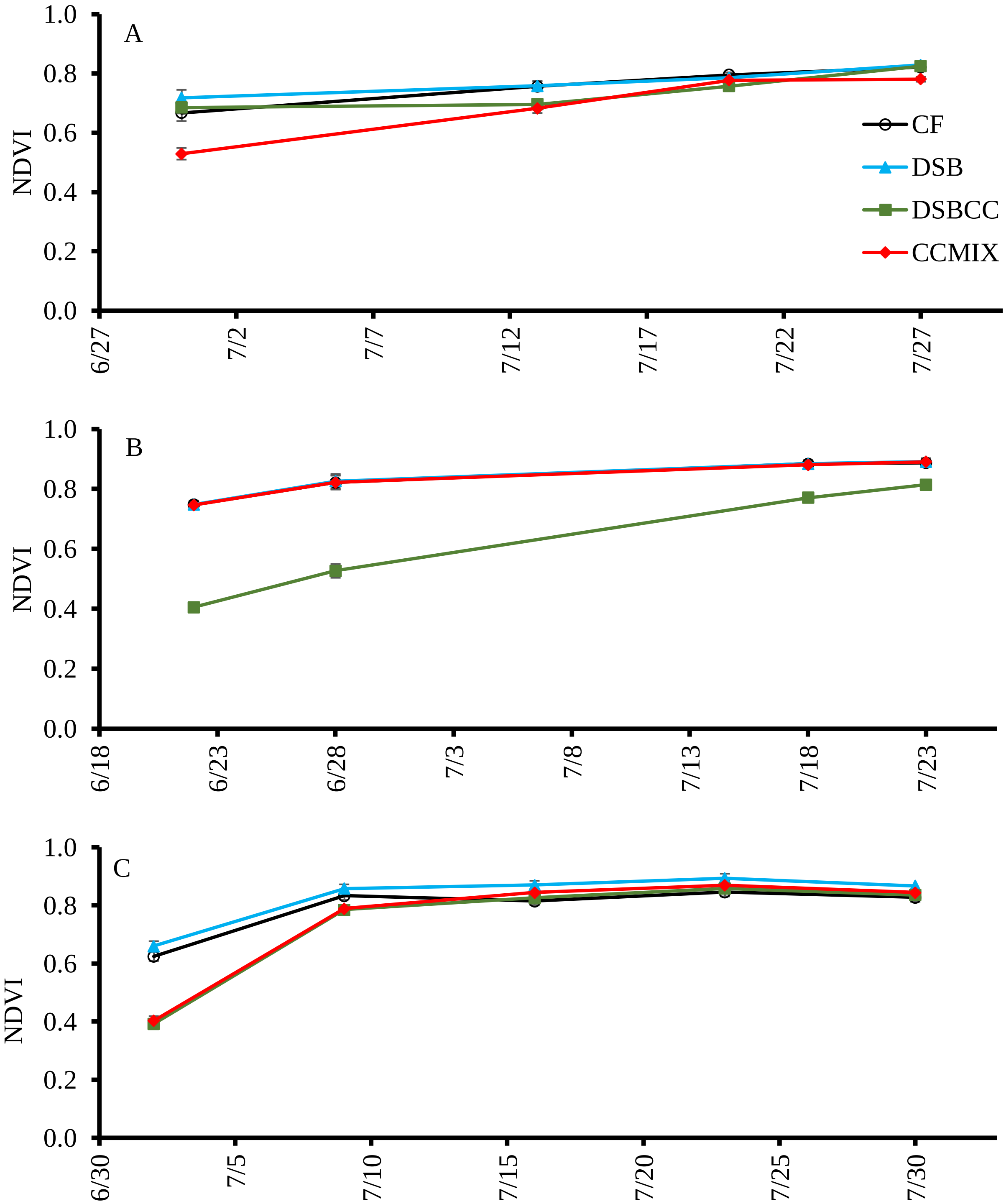


Figure 3.4. Cover crop effect on NDVI in 2017 (A), 2018 (B), and 2019 (C) during sorghum growth and development at Manhattan, KS 2017 to 2019. Treatments: chemical fallow (CF), double-crop soybean (DSB), double-crop soybean plus spring cover crop (DSBCC), summer cover crop mixture after wheat (CCMIX).

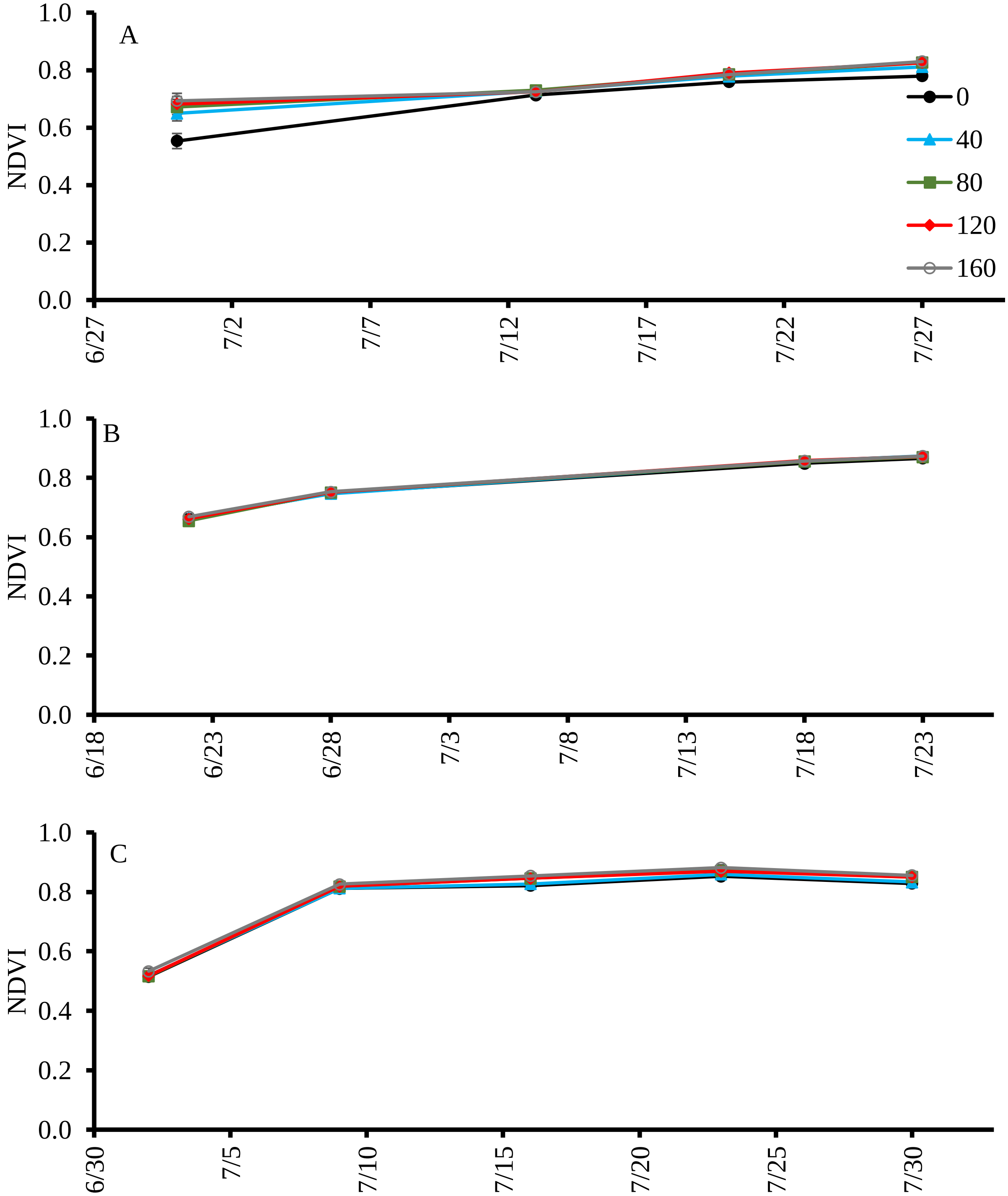


Figure 3.5. Nitrogen fertilizer rate effect on NDVI in 2017 (A), 2018 (B), and 2019 (C) during sorghum growth and development at Manhattan, KS 2017 to 2019. 0, 40, 80, 120, 160 pounds acre^{-1} of N fertilizer applied at sorghum planting.

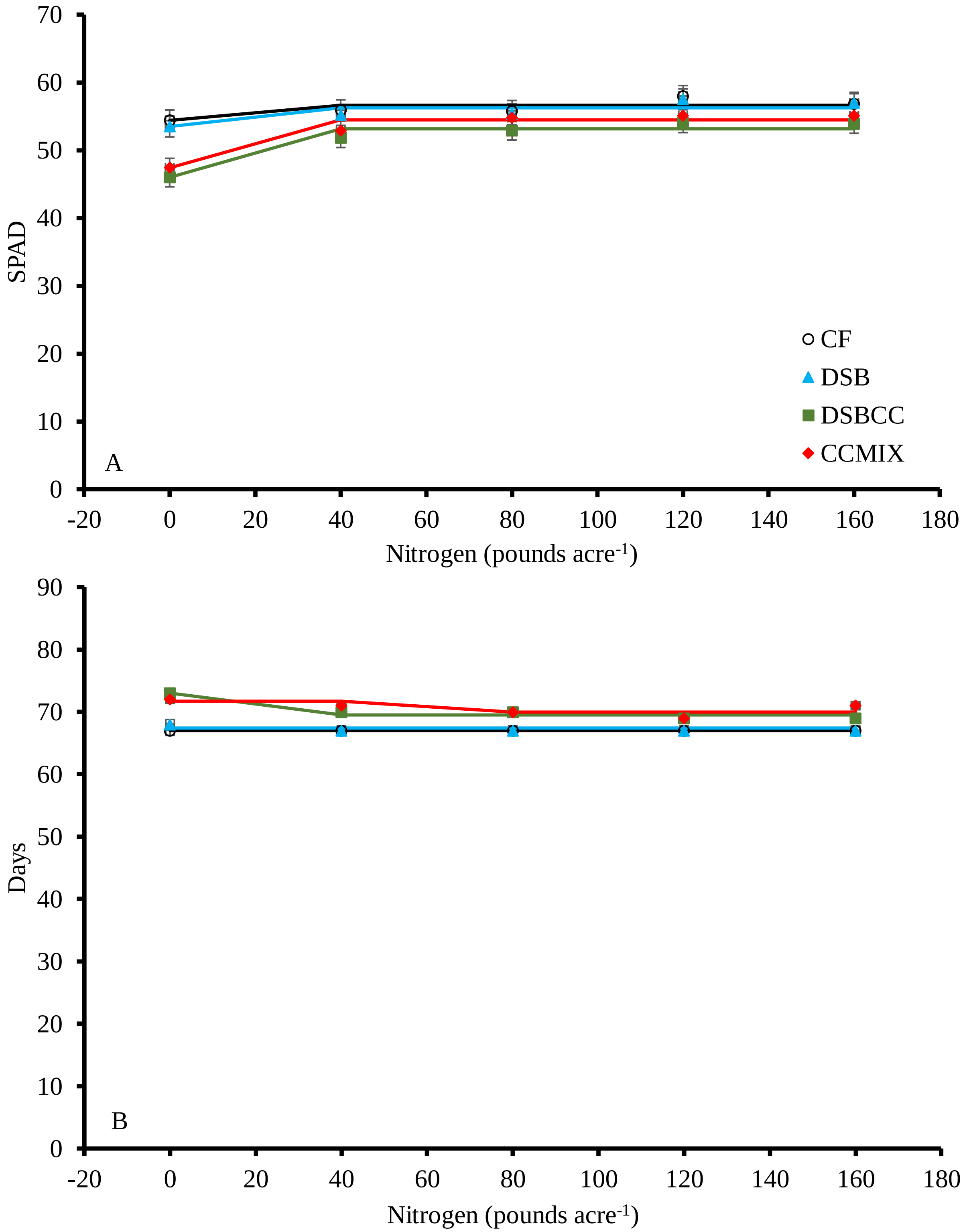


Figure 3.6. Cover crop×nitrogen interaction for SPAD (A) and half-bloom (B) during sorghum growth and development at Manhattan, KS 2017. Treatments: chemical fallow (CF), double-crop soybean (DSB), double-crop soybean plus spring cover crop (DSBCC), summer cover crop mixture after wheat (CCMIX).

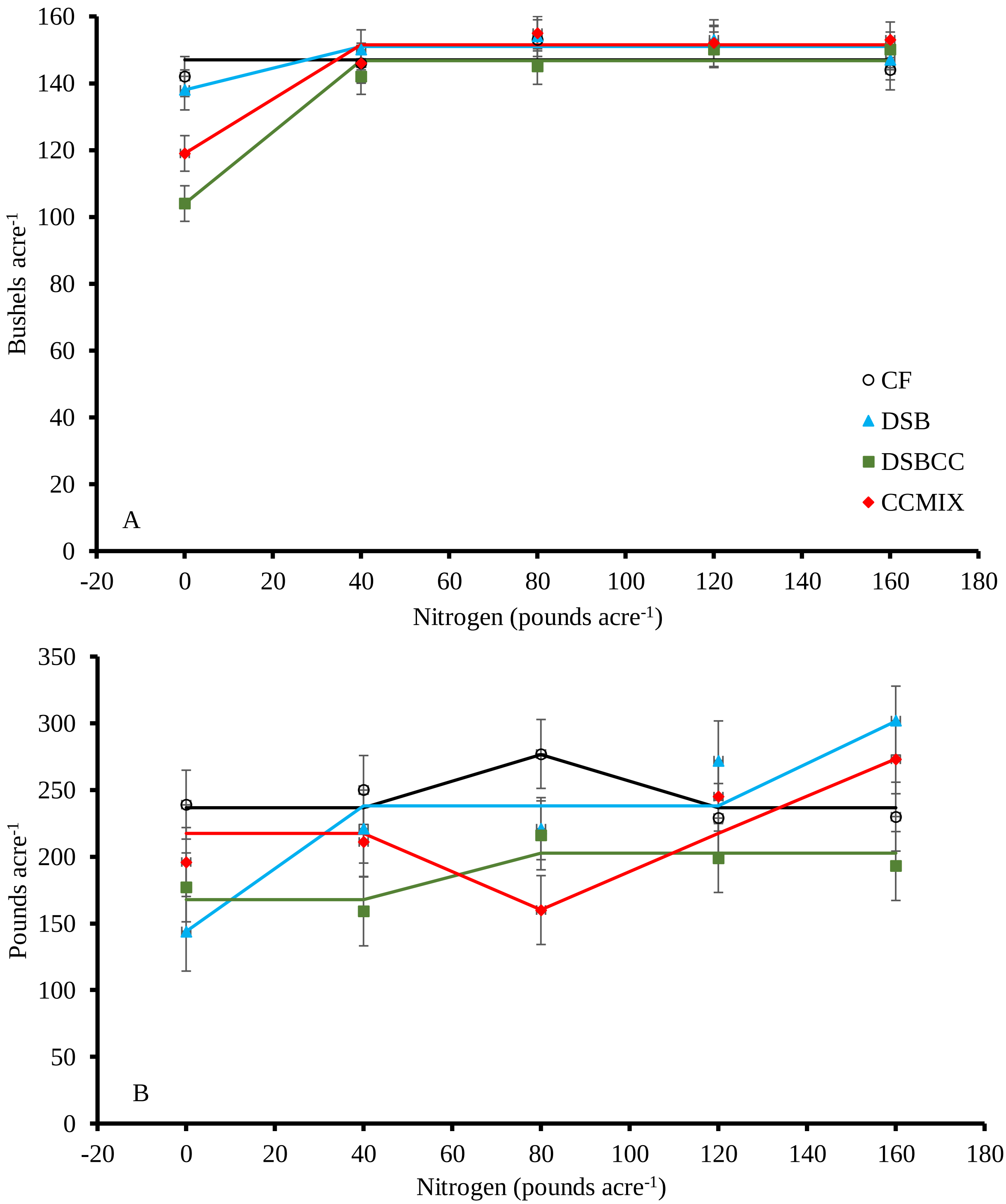
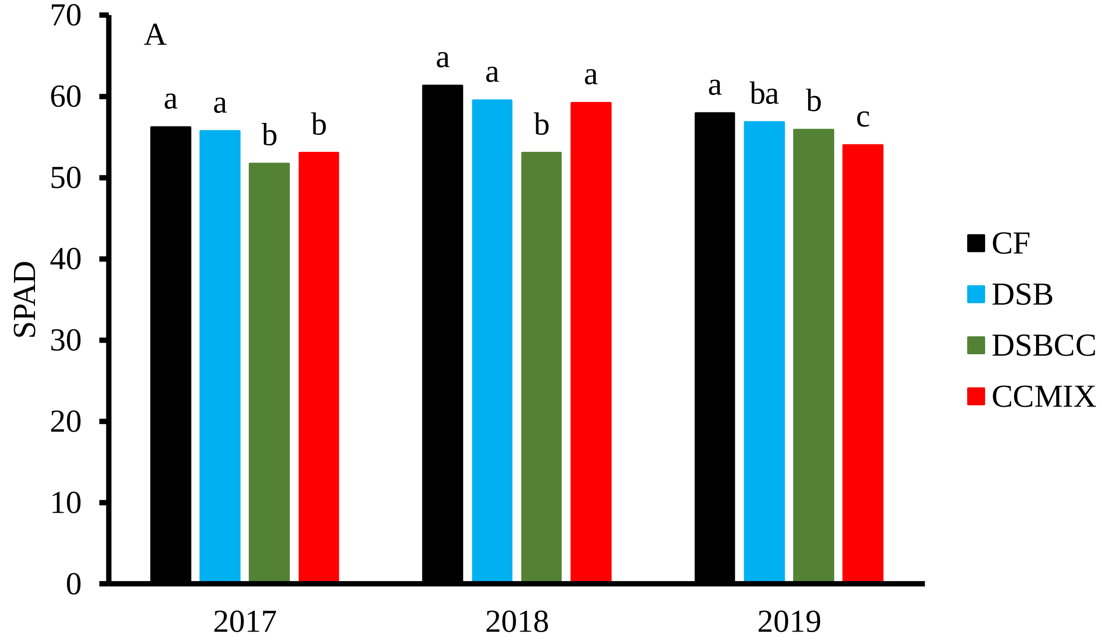


Figure 3.7. Cover crop×nitrogen interaction for yield (A), and N uptake (B) during sorghum growth and development at Manhattan, KS 2017-2018. Treatments: chemical fallow (CF), double-crop soybean (DSB), double-crop soybean plus spring cover crop (DSBCC), summer cover crop mixture after wheat (CCMIX).



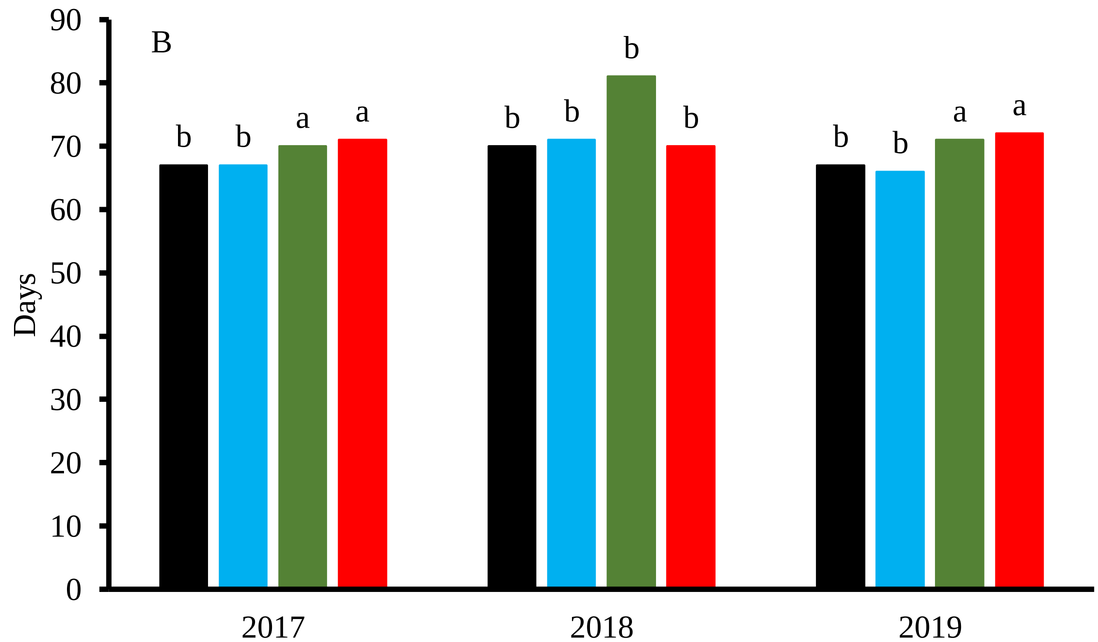


Figure 3.8. Cover crop effect for SPAD (A) and half-bloom (B) during sorghum growth and development at Manhattan, KS 2017-2019. Treatments: chemical fallow (CF), double-crop soybean (DSB), double-crop soybean plus spring cover crop (DSBCC), summer cover crop mixture after wheat (CCMIX). Treatments within a year with the same lower-case letter above the bar are not significantly different (α= 0.05).

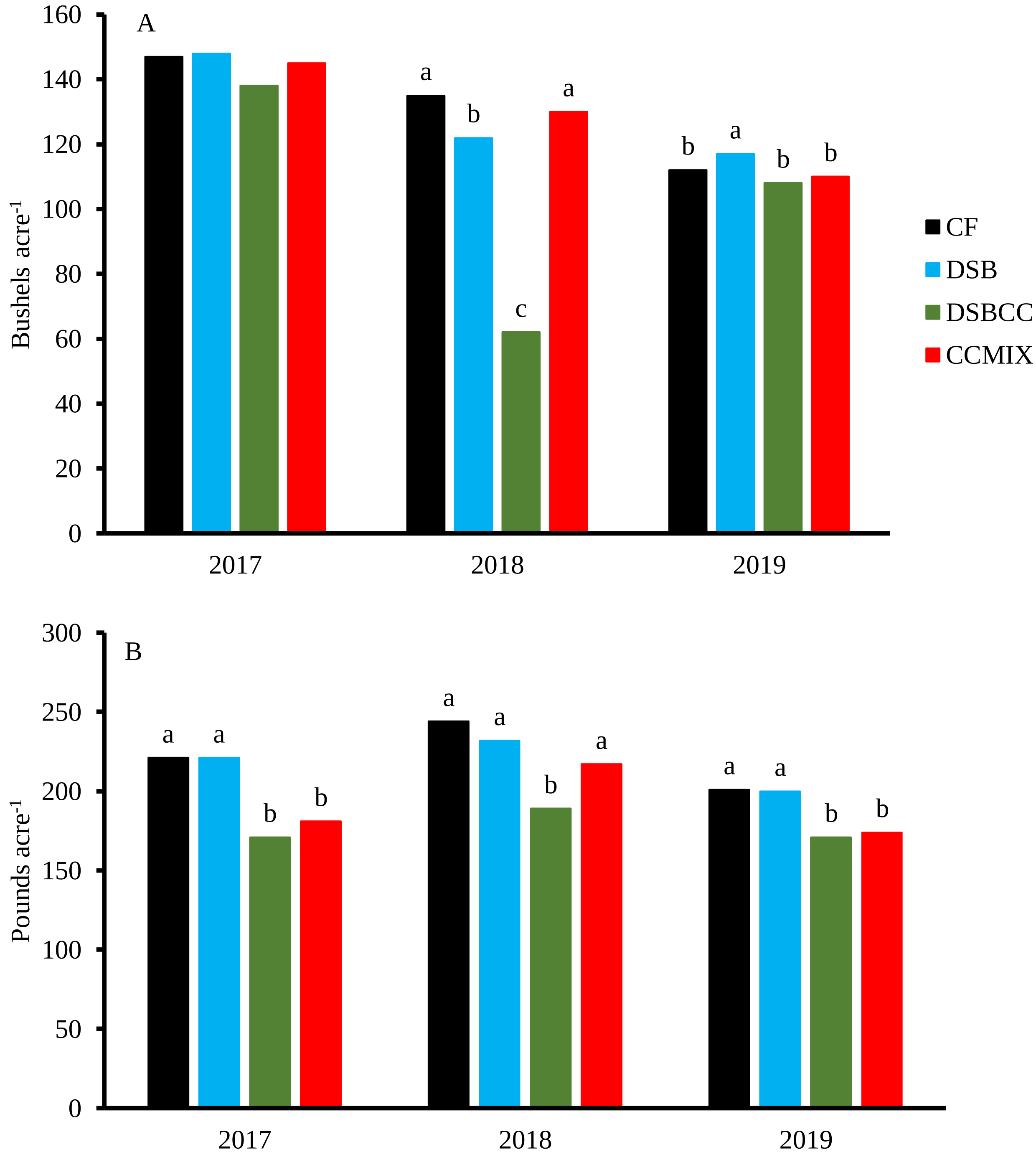


Figure 3.9. Cover crop effect for yield (A), and N uptake (B) during sorghum growth and development at Manhattan, KS 2017 to 2019. Treatments: chemical fallow (CF), double-crop soybean (DSB), double-crop soybean plus a spring cover crop (DSBCC), summer cover crop mixture after wheat (CCMIX). Treatments within a year with the same lower-case letter above the bar are not significantly different (α= 0.05).

Table 3.1. Tests of significance for sorghum response to cover crop, nitrogen rate, and their interactions for percent canopy cover and normalized difference vegetative index (NDVI) at each sample date in 2018 to 2019 (canopy cover) and 2017 to 2019 (NDVI).

Season	Source of Variation		
Date	Cover crop (CC)	Nitrogen (N)	CC×N
	——————— Probability of >F ———————		
Canopy cover			
2018			
6-29	<0.001	0.386	0.996
7-5	<0.001	0.901	0.966
7-11	<0.001	0.300	0.959
7-20	<0.001	0.968	0.979
7-25	<0.001	0.965	0.873
7-31	<0.001	0.967	0.929
8-7	<0.001	<0.001	0.983
8-14	<0.001	<0.001	0.829
2019			
7-2	<0.001	0.235	0.736
7-9	0.011	0.301	1.000
7-16	0.255	0.039	0.452
7-23	0.579	0.716	0.571
7-30	0.361	0.001	0.038
NDVI			
2017			
30 June	<0.001	0.001	1.000
13 July	0.010	0.532	0.965
20 July	0.005	<0.001	0.170
27 July	<0.001	0.001	0.895
2018			
6-22	<0.001	0.501	0.796
6-28	<0.001	0.987	1.000
7-18	<0.001	0.674	0.976
7-23	<0.001	0.569	0.997
2019			
7-2	<0.001	0.350	0.797
7-9	0.006	0.669	0.973
7-16	0.108	0.024	0.951
7-23	0.230	0.010	0.666
7-30	0.282	0.019	0.558

Table 3.2. Tests of significance for sorghum response variables to main effects of cover crop, nitrogen rate, and their interaction at Manhattan, KS, 2017-2019.

	Source of variation						
Response variable† Season	Cover crop (CC)	Nitrogen (N)	CC×N	Year (Y)	Y×CC	Y×N	Y×CC×N
	Probability of >F						
SPAD	0.001	<0.001	0.102	<0.001	<0.001	0.008	0.832
Days to half bloom	<0.001	<0.001	0.849	<0.001	<0.001	<0.001	0.304
Plant height	<0.001	0.227	0.960	<0.001	<0.001	0.958	0.894
Plants $acre^{-1}$	0.103	0.561	0.381	<0.001	<0.001	0.397	0.586
Heads $plant^{-1}$	0.022	0.901	0.874	<0.001	<0.001	0.951	0.990
Head size	0.004	<0.001	0.560	<0.001	<0.001	0.811	0.978
Grain yield	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.460
Seed size	0.004	0.009	0.049	<0.001	<0.001	0.378	0.702
Test weight	0.017	0.024	0.203	<0.001	0.010	0.274	0.683
Biomass yield	<0.001	<0.001	0.011	<0.001	<0.001	0.007	0.465
Harvest index	0.185	0.697	0.509	<0.001	0.090	0.897	0.918
Stover %N	0.003	<0.001	0.002	0.001	<0.001	<0.001	0.572
Grain %N	0.002	<0.001	0.009	<0.001	0.003	<0.001	0.113
N uptake	0.006	<0.001	0.001	<0.001	0.317	<0.001	0.065

Table 3.3. Sorghum biomass after cover crops in a no-till three-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2017 to 2019.

Season N-rates‡	CF	DSB	DSBCC	CCMIX	N-rate mean
	Cover crop treatment†				
	pounds acre^{-1}				
2017					
0	15016	15169	11676	12734	13649C§
40	15371	15794	13835	16084	15271B
80	16591	16179	14532	16536	15960BA
120	17180	17252	16491	16077	16750A
160	15784	16672	15877	16589	16231A
Trt. mean	15988A	16214A	14482B	15604A	
2018					
0	17543	15110	11987	16270	15227
40	17585	18663	12111	16956	16329
80	19131	16603	13723	15491	16237
120	17064	17744	13712	17514	16509
160	17779	19083	13477	18518	17214
Trt. mean	17820A	17441A	13002B	16950A	
2019					
0	15860ba	15474bac	13647dec	13086de	14517
40	15391bdac	15977ba	12829e	13934bdec	14533
80	15922ba	15137bdc	15069bdc	14712bdec	15210
120	12675e	17556a	14691bdec	13980bdec	14726
160	14367bdec	14553bdec	14246bdec	14223bdec	14347
Trt. mean	14843BA	15739A	14097B	13987B	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.
‡Nitrogen rates: values indicate N applied as pounds acre^{-1}.
§Differences between main effect means followed by the same uppercase letter and between interaction means followed by the same lowercase letter are not significant at $\alpha = 0.05$.

Appendix A - Sorghum response to cover crops

Table A.1. Vegetative response of sorghum, separated by date and treatment mean, as affected by previous cover crop in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2018-2019.

Season	Cover crop treatment†			
dates	CF	DSB	DSBCC	CCMIX
	————————% cover ————————			
2018				
29 June	70.0A‡	70.3A	39.1B	69.7A
5 July	83.7A	84.3A	43.6B	83.2A
11 July	77.4A	74.1A	38.0B	75.0A
20 July	93.5A	92.3A	67.2B	93.1A
25 July	89.3A	87.9A	68.6B	87.5A
31 July	81.8A	79.2A	68.8B	80.7A
7 Aug.	85.3A	81.7B	73.2C	82.7B
14 Aug.	84.0A	79.7B	72.5C	81.5BA
2019				
2 July	40.7A	42.5A	20.6B	21.6B
9 July	83.7A	90.3A	68.0B	69.5B
16 July	83.1	89.6	79.0	81.9
23 July	80.4	87.4	84.2	85.5
30 July	86.8	92.0	87.8	88.8

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡ Differences between main effect means followed by the same uppercase letter are not significant at $\alpha = 0.05$.

Table A.2. Vegetative response of sorghum, separated by date and nitrogen mean, as affected by previous cover crop in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2018-2019.

Season dates	Season N-rates† 0	40	80	120	160
	——————— % cover ———————				
2018					
29 June	61.2	62.5	62.3	62.2	63.0
5 July	72.8	74.0	73.6	73.9	74.2
11 July	64.6	66.5	66.0	67.0	66.5
20 July	86.2	86.8	86.5	86.6	86.6
25 July	83.5	83.3	83.3	83.7	82.8
31 July	77.7	78.0	77.5	77.4	77.5
7 Aug.	77.6B‡	81.0A	81.6A	81.5A	82.0A
14 Aug.	74.9C	78.6B	80.4BA	81.4A	81.3A
2019					
2 July	30.5	31.7	30.7	31.3	32.5
9 July	75.3	76.9	79.3	78.7	79.3
16 July	81.5B	82.1B	85.1A	83.5BA	84.8A
23 July	85.0	83.9	85.1	83.5	84.3
30 July	86.6C	88.8BA	90.5A	88.2BC	90.0BA

† Nitrogen rates: values indicate N applied as pounds $acre^{-1}$.

‡ Differences between main effect means followed by the same uppercase letter are not significant at $\alpha = 0.05$.

Table A.3. Sorghum NDVI readings, separated by date and treatment mean, as affected by previous cover crops and N rates in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2017-2019.

Season dates	Cover crop treatment†			
	CF	DSB	DSBCC	CCMIX
	——————— NDVI———————			
2017				
30 June	0.67A‡	0.72A	0.69A	0.53B
13 July	0.76A	0.76A	0.70B	0.68B
20 July	0.80A	0.79B	0.76C	0.78B
27 July	0.82A	0.83A	0.82A	0.78B
2018				
22 June	0.75A	0.75A	0.41B	0.75A
28 June	0.82A	0.83A	0.53B	0.82A
18 July	0.88A	0.88A	0.77B	0.88A
23 July	0.89A	0.89A	0.81B	0.89A
2019				
2 July	0.62A	0.66A	0.39B	0.40B
9 July	0.84A	0.86A	0.79B	0.79B
16 July	0.81	0.87	0.83	0.84
23 July	0.85	0.89	0.86	0.87
30 July	0.83	0.87	0.84	0.84

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡ Differences between main effect means followed by the same uppercase letter are not significant at $\alpha = 0.05$.

Table A.4. Sorghum NDVI readings, separated by date and nitrogen rate means, as affected by previous cover crops and N rates in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2017-2019.

Season	Season N-rates†				
dates	0	40	80	120	160
	———————— NDVI ————————				
2017					
30 June	0.55B‡	0.65A	0.67A	0.68A	0.63A
13 July	0.71	0.73	0.73	0.72	0.72
20 July	0.76C	0.78B	0.78BA	0.79A	0.78BA
27 July	0.78B	0.81A	0.83A	0.83A	0.83A
2018					
22 June	0.66	0.66	0.66	0.66	0.67
28 June	0.75	0.75	0.75	0.75	0.75
18 July	0.85	0.86	0.86	0.86	0.86
23 July	0.87	0.87	0.87	0.87	0.87
2019					
2 July	0.51	0.52	0.52	0.52	0.53
9 July	0.81	0.81	0.82	0.82	0.83
16 July	0.82C	0.83BC	0.85BA	0.85BA	0.85A
23 July	0.85C	0.86BC	0.87BA	0.87BAC	0.88A
30 July	0.83C	0.83BC	0.85BA	0.85BA	0.86A

† Nitrogen rates: values indicate N applied as pounds $acre^{-1}$.

‡ Differences between main effect means followed by the same uppercase letter are not significant at $\alpha = 0.05$.

Table A.5. Tests of significance for sorghum in-season response to main effects of cover crop, nitrogen rate, and their interaction at Manhattan, KS, 2017-2019.

Season	Source of Variation		
Date	Cover crop (CC)	Nitrogen (N)	CC×N
	———————— Probability of >F ————————		
SPAD			
2017	0.002	<0.001	0.004
2018	<0.001	0.001	0.277
2019	<0.001	<0.001	0.996
Bloom			
2017	0.004	<0.001	0.006
2018	<0.001	0.966	0.955
2019	<0.001	<0.001	0.673
Plant height			
2017	0.154	0.473	0.179
2018	<0.001	0.610	0.970
2019	0.315	0.378	0.662
Plants acre-1			
2017	0.036	0.430	0.796
2018	0.389	0.640	0.734
2019	0.001	0.231	0.016
Heads plant-1			
2017	0.321	0.361	0.362
2018	0.006	0.889	0.993
2019	0.444	0.968	0.256
Head size			
2018	<0.001	0.002	0.500
2019	0.547	<0.001	0.940

Table A.6. Chlorophyll status of sorghum grown after cover crops and receiving different N rates as indicated by SPAD readings take at half bloom in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS from 2017-2019.

Season	Cover crop treatment†				N-rate
N-rates‡	CF	DSB	DSBCC	CCMIX	mean
			SPAD		
2017					
0	54.4edfc	53.5edf	46.0g	47.4g	50.3D§
40	55.9bdac	55.2ebdac	51.8f	52.9ef	54.0C
80	55.8bdac	55.3ebdac	52.6ef	54.8edc	54.7BC
120	58.0a	57.5ba	54.0edf	55.1ebdc	56.1A
160	56.8bac	57.0bac	53.9edf	55.1ebdc	55.7BA
Trt. mean	56.2A	55.7A	51.7B	53.0B	
2018					
0	62.1	55.8	46.6	55.6	55.0B
40	60.1	60.0	54.8	59.1	58.5A
80	59.7	61.3	53.2	59.9	58.5A
120	63.4	61.8	54.9	62.4	60.5A
160	61.1	59.1	55.8	58.9	58.7A
Trt. mean	61.3A	59.5A	53.0B	59.2A	
2019					
0	52.4	51.5	50.1	47.9	50.5D
40	55.5	54.6	53.5	50.9	53.6C
80	60.0	57.3	57.3	56.4	57.7B
120	61.1	60.8	59.9	57.5	59.8A
160	60.5	59.8	58.6	57.4	59.1BA
Trt. mean	57.9A	56.8BA	55.9B	54.0C	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡Nitrogen rates: values indicate N applied as pounds $acre^{-1}$.

§Differences between main effect means followed by the same uppercase letter and between interaction means followed by the same lowercase letter are not significant at $\alpha = 0.05$.

Table A.7. Days from planting to half bloom of sorghum, as affected by previous cover crop and nitrogen rate in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS, 2017-2019.

Season	Cover crop treatment†				N-rate
N-rates‡	CF	DSB	DSBCC	CCMIX	mean
	—————————— days ——————————				
2017					
0	66.8f	68.0efd	72.8a	72.0a	69.9A§
40	67.3ef	67.3ef	69.8bcd	71.4ba	68.9B
80	66.8f	67.3ef	69.3cd	70.0bc	68.3CB
120	66.8f	67.0f	69.0ecd	69.4cd	68.0C
160	67.3ef	67.3ef	69.3cd	70.5bc	68.6CB
Trt. mean	67.0B	67.4B	70.0A	70.7A	
2018					
0	70.5	70.5	81.1	70.5	73.2
40	70.3	70.5	81.4	70.4	73.1
80	70.3	70.5	81.4	70.4	73.1
120	70.3	70.5	81.3	70.4	73.1
160	70.0	70.5	81.4	70.4	73.1
Trt. mean	70.3B	70.5B	81.3A	70.4B	
2019					
0	69.5	68.0	73.1	73.4	71.0A
40	67.8	65.8	71.3	71.5	69.1B
80	66.0	65.5	70.3	71.3	68.3CB
120	65.3	65.5	70.3	71.6	68.2C
160	65.5	65.8	70.0	71.6	68.2CB
Trt. mean	66.8B	66.1B	71.0A	71.9A	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡Nitrogen rates: values indicate N applied as pounds acre^{-1}.

§Differences between main effect means followed by the same uppercase letter and between interaction means followed by the same lowercase letter are not significant at $\alpha = 0.05$.

Table A.8. Height of sorghum as affected by previous cover crop and nitrogen rate in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2017-2019.

Season N-rates‡	Cover crop treatment† CF	DSB	DSBCC	CCMIX	N-rate mean
	———————————	———————	in	———————	———————————
2017					
0	46.2	45.2	43.1	44.1	44.6
40	45.3	45.0	44.6	45.8	45.2
80	45.6	44.7	44.6	45.6	45.1
120	45.9	44.3	44.8	45.9	45.2
160	45.9	44.9	44.0	45.7	45.1
Trt. mean	45.8	44.8	44.2	45.4	
2018					
0	45.3	45.3	35.9	44.9	42.8
40	46.1	45.5	35.9	45.4	43.2
80	46.5	45.0	36.3	45.5	43.3
120	46.4	44.7	36.7	45.3	43.3
160	46.4	45.8	37.7	45.2	43.7
Trt. mean	46.1A§	45.2A	36.5B	45.2A	
2019					
0	51.9	53.7	52.7	53.1	52.8
40	52.8	53.7	52.7	53.6	53.2
80	54.3	54.0	53.0	53.3	53.6
120	51.0	54.3	52.4	53.6	52.8
160	53.4	54.3	52.4	53.7	53.4
Trt. mean	52.7	54.0	52.6	53.4	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡Nitrogen rates: values indicate N applied as pounds acre^{-1}.

§Differences between main effect means followed by the same uppercase are not significant at $\alpha = 0.05$.

Table A.9. Population response of sorghum grown after cover crops under a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS from 2017-2019

Season	Cover crop treatment†				N-rate
N-rates‡	CF	DSB	DSBCC	CCMIX	mean
	——— plants acre^{-1} ———				
2017					
0	69043	66429	66048	64142	66415
40	66974	65776	60331	60548	63407
80	68825	68498	63924	61746	65748
120	64796	68498	66102	57935	64333
160	66211	67409	63325	61311	64564
Trt. mean	67170A§	67322A	63946BA	61136B	
2018					
0	65884	65122	66865	66592	66116
40	64360	63924	68553	65177	65503
80	64033	66538	69043	66919	66633
120	64251	66538	68770	64904	66116
160	65340	64033	66048	65721	65286
Trt. mean	64774	65231	67856	65863	
2019					
0	78190ba	72636edgf	71602ehgf	72691edgf	73780
40	73181edgcf	77537bdac	69043hg	74596ebdac	73589
80	74488ebdacf	77428bdac	70240hgf	68117h	72568
120	77863bac	77537bdac	70240hgf	74052ebdcf	74923
160	74161ebdacf	78844a	70785hgf	74488ebdacf	74569
Trt. mean	75577A	76796A	70382C	72789B	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡Nitrogen rates: values indicate N applied as pounds acre^{-1}.

§Differences between main effect means followed by the same uppercase letter and between interaction means followed by the same lowercase letter are not significant at $\alpha = 0.05$.

Table A.10. Number of sorghum heads per plant in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2017-2019.

Season N-rates‡	Cover crop treatment† CF	DSB	DSBCC	CCMIX	N-rate mean
	——————heads plant^{-1}——————				
2017					
0	0.95	0.97	0.94	0.91	0.94
40	0.95	0.98	0.94	0.96	0.96
80	0.95	0.94	0.90	0.94	0.93
120	1.00	0.98	0.89	0.99	0.97
160	0.99	0.96	0.95	0.96	0.96
Trt. mean	0.97	0.96	0.92	0.95	
2018					
0	1.02	1.01	0.75	1.02	0.95
40	1.05	0.99	0.72	0.96	0.93
80	1.05	0.93	0.72	0.98	0.92
120	1.06	0.96	0.73	0.97	0.93
160	1.02	0.98	0.76	0.96	0.93
Trt. mean	1.04A§	0.97A	0.74B	0.98A	
2019					
0	0.83	0.93	0.84	0.89	0.87
40	0.91	0.82	0.84	0.87	0.86
80	0.84	0.86	0.86	0.94	0.88
120	0.89	0.85	0.86	0.89	0.87
160	0.85	0.88	0.86	0.90	0.87
Trt. mean	0.86	0.87	0.85	0.90	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.
‡Nitrogen rates: values indicate N applied as pounds acre^{-1}.
§Differences between main effect means followed by the same uppercase are not significant at $\alpha = 0.05$.

Table A.11. Head size of sorghum as affected by previous cover crops grown under a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS from 2018 to 2019.

Season	Cover crop treatment†				N-rate
N-rates‡	CF	DSB	DSBCC	CCMIX	mean
	——————seed/ head ——————				
2018					
0	1849	1859	948	1789	1611B§
40	1893	1952	1203	2025	1768A
80	2013	2020	1129	2016	1795A
120	1920	1925	1118	2034	1749A
160	2020	1929	1322	1966	1809A
Trt. mean	1939A	1937A	1144B	1966A	
2019					
0	1418	1471	1410	1334	1408D
40	1504	1566	1578	1510	1539C
80	1642	1594	1663	1639	1654BA
120	1532	1603	1615	1538	1572BC
160	1710	1613	1711	1608	1660A
Trt. mean	1561	1569	1595	1526	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡Nitrogen rates: values indicate N applied as pounds $acre^{-1}$.

§Differences between main effect means followed by the same uppercase are not significant at $\alpha = 0.05$.

Table A.12. Tests of significance for sorghum harvest response to main effects of cover crop, nitrogen rate, and their interaction at Manhattan, KS, 2017-2019.

Season	Source of Variation		
Date	Cover crop (CC)	Nitrogen (N)	CC×N
	———————— Probability of >F ————————		
Yield			
2017	0.088	<0.001	<0.001
2018	<0.001	0.109	0.219
2019	0.005	<0.001	0.171
Seed size			
2018	0.001	0.056	0.104
2019	0.586	0.002	0.484
Test weight			
2017	0.001	<0.001	0.996
2018	0.180	0.084	0.103
2019	0.559	0.378	0.841
Harvest index			
2017	0.287	0.706	0.285
2018	0.005	0.728	0.847
2019	0.456	0.477	0.797
Stover %N			
2017	0.001	<0.001	0.026
2018	0.207	0.101	0.071
2019	0.008	0.007	0.875
Grain %N			
2017	0.030	<0.001	0.003
2018	0.018	0.009	0.014
2019	0.507	0.004	0.999
N uptake			
2017	0.002	<0.001	0.192
2018	0.007	0.017	0.035
2019	0.002	0.004	0.327

Table A.13. Yield response of sorghum as affected by previous cover crop grown under a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS from 2017-2019.

Season	Cover crop treatment†				N-rate
N-rates‡	CF	DSB	DSBCC	CCMIX	mean
	——— bushels ac^{-1} ———				
2017					
0	142.4bdc	137.7d	104.5f	118.8e	125.8C§
40	145.8bdac	150.2bac	141.9dc	146.1bdac	146.0B
80	153.0bac	153.6ba	144.6bdac	155.1a	151.6A
120	150.1bdac	153.0bac	150.3bac	152.2bac	151.4A
160	143.9bdac	147.0bdac	150.1bac	153.3ba	148.6BA
Trt. mean	147.0	148.3	138.3	145.1	
2018					
0	133.5	121.8	50.4	122.2	107.0
40	133.7	121.8	61.7	128.1	111.3
80	141.6	121.9	59.6	137.3	115.1
120	135.7	126.4	64.0	134.6	115.2
160	131.3	118.0	72.0	127.1	112.1
Trt. mean	135.2A	122.0B	61.5C	129.9A	
2019					
0	100.8	109.2	92.30	93.00	98.84D
40	108.6	111.3	101.5	107.0	107.1C
80	112.9	119.2	113.7	116.4	115.6B
120	117.2	119.2	114.7	114.9	116.5B
160	119.2	124.3	119.1	120.7	120.8A
Trt. mean	111.8B	116.7A	108.3B	110.4B	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡Nitrogen rates: values indicate N applied as pounds acre^{-1}.

§Differences between main effect means followed by the same uppercase letter and between interaction means followed by the same lowercase letter are not significant at $\alpha = 0.05$.

Table A.14. Seed weight of sorghum as affected by previous cover crop and nitrogen rate in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2018-2019.

Season	Cover crop treatment†				N-rate
N-rates‡	CF	DSB	DSBCC	CCMIX	mean
	——————————— grams 300 sd^{-1} ———————————				
2018					
0	8.8	8.3	8.9	8.3	8.5
40	8.6	8.0	8.9	8.3	8.5
80	8.6	8.1	9.5	8.5	8.7
120	8.5	8.4	9.6	8.6	8.8
160	8.0	8.1	9.3	8.5	8.5
Trt. mean	8.5B§	8.2B	9.2A	8.4B	
2019					
0	9.0	9.0	8.9	8.9	8.9C
40	9.0	9.1	9.1	8.9	9.0BC
80	9.0	9.2	9.2	9.2	9.1BA
120	9.1	9.2	9.5	9.3	9.3A
160	9.1	9.1	9.4	9.2	9.2A
Trt. mean	9.0	9.1	9.2	9.1	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡Nitrogen rates: values indicate N applied as pounds $acre^{-1}$.

§Differences between main effect means followed by the same uppercase are not significant at $\alpha = 0.05$.

Table A.15. Sorghum grain test weight after previous cover crops in a no-till three-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS from 2017 to 2019.

Season	Cover crop treatment†				N-rate
N-rates‡	CF	DSB	DSBCC	CCMIX	mean
	——————————pounds bushel^{-1}——————————				
2017					
0	60.3	60.6	61.2	61.2	60.8A§
40	60.4	60.6	61.1	61.1	60.8A
80	60.1	60.4	60.9	60.8	60.6B
120	60.1	60.3	60.8	60.7	60.5B
160	60.1	60.2	60.8	60.8	60.5B
Trt. mean	60.2B	60.4B	61.0A	60.9A	
2018					
0	58.5	58.0	57.9	57.6	58.0
40	57.9	57.6	57.3	57.8	57.6
80	57.9	54.1	57.2	58.0	56.8
120	57.8	57.2	57.2	57.7	57.4
160	57.6	56.8	56.8	57.6	57.3
Trt. mean	57.9	56.8	57.3	57.7	
2019					
0	61.2	61.5	61.3	61.5	61.4
40	61.2	61.3	61.3	61.5	61.3
80	61.3	61.3	61.5	61.6	61.4
120	61.0	61.2	61.5	61.4	61.3
160	61.1	61.0	59.9	61.3	60.8
Trt. mean	61.1	61.3	61.1	61.4	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.
‡Nitrogen rates: values indicate N applied as pounds acre^{-1}.
§Differences between main effect means followed by the same uppercase are not significant at $\alpha = 0.05$.

Table A.16. Harvest index of sorghum as affected by previous cover crop in a no-till three-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2017 to 2019.

Season	Cover crop treatment†				N-rate
N-rates‡	CF	DSB	DSBCC	CCMIX	mean
	————————————Index————————————				
2017					
0	40.8	41.3	37.3	38.1	39.4
40	38.4	34.1	45.2	45.2	40.7
80	39.5	38.1	42.6	43.2	40.8
120	39.5	40.6	40.7	42.0	40.7
160	35.8	39.5	37.1	42.2	38.7
Trt. mean	38.8	38.7	40.6	42.1	
2018					
0	40.9	37.3	36.8	42.1	39.3
40	39.6	39.7	38.0	40.3	39.4
80	40.5	36.7	37.9	38.0	38.3
120	39.7	39.3	38.1	41.3	39.6
160	40.7	36.5	37.2	40.5	38.7
Trt. mean	40.3A§	37.9B	37.6B	40.4A	
2019					
0	34.6	36.0	34.9	33.5	34.8
40	33.9	35.4	39.8	35.8	36.2
80	39.2	35.9	37.0	36.5	37.2
120	34.9	37.2	37.5	35.3	36.2
160	36.2	36.3	36.5	37.2	36.5
Trt. mean	35.8	36.1	37.2	35.7	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡Nitrogen rates: values indicate N applied as pounds $acre^{-1}$.

§Differences between main effect means followed by the same uppercase are not significant at $\alpha = 0.05$.

Table A.17. Nitrogen content, represented as a percentage, of sorghum stover in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2017-2019.

Season	Cover crop treatment†				N-rate
N-rates‡	CF	DSB	DSBCC	CCMIX	mean
	——— percent ———				
2017					
0	0.9fg	0.9fhg	0.7ih	0.7i	0.8E§
40	1.1cbd	0.9feg	0.8fihg	0.8ihg	0.9D
80	1.3b	1.3b	0.9feg	1.0fed	1.1C
120	1.5a	1.5a	1.2cb	1.1ced	1.3B
160	1.6a	1.6a	1.2b	1.3b	1.4A
Trt. mean	1.3A	1.2A	1.0B	1.0B	
2018					
0	1.2	0.9	1.3	1.1	1.1
40	1.3	1.0	1.1	1.1	1.1
80	1.3	1.2	1.4	0.9	1.2
120	1.2	1.4	1.3	1.3	1.3
160	1.1	1.5	1.3	1.3	1.3
Trt. mean	1.2	1.2	1.3	1.1	
2019					
0	1.1	1.0	1.0	0.9	1.0C
40	1.2	1.0	0.9	1.0	1.0BC
80	1.2	1.2	1.1	1.0	1.1BA
120	1.2	1.3	1.0	1.1	1.1BA
160	1.3	1.2	1.1	1.2	1.2A
Trt. mean	1.2A	1.1BA	1.0B	1.0B	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.
‡Nitrogen rates: values indicate N applied as pounds $acre^{-1}$.
§Differences between main effect means followed by the same uppercase letter and between interaction means followed by the same lowercase letter are not significant at $\alpha = 0.05$.

Table A.18. Nitrogen content, represented as a percentage, of sorghum grain in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2017-2019.

Season	Cover crop treatment†				N-rate
N-rates‡	CF	DSB	DSBCC	CCMIX	mean
	———————————— percent ————————————				
2017					
0	1.3gf	1.3gf	1.1h	1.1h	1.2E§
40	1.4ed	1.4ef	1.3gf	1.2g	1.3D
80	1.6dc	1.6bc	1.4e	1.4e	1.5C
120	1.7bac	1.7bac	1.6bac	1.6dc	1.6B
160	1.7bac	1.7a	1.7ba	1.6bac	1.7A
Trt. mean	1.5BA	1.5A	1.4BC	1.4C	
2018					
0	1.6bac	1.1e	1.7bac	1.4edc	1.4B
40	1.6bac	1.4dc	1.5dc	1.5dc	1.5B
80	1.7bac	1.6bac	1.7ba	1.3ed	1.6BA
120	1.6bac	1.7bac	1.7ba	1.6bac	1.7A
160	1.5bdc	1.8a	1.6bac	1.6bac	1.6A
Trt. mean	1.6BA	1.5B	1.7A	1.5B	
2019					
0	1.5	1.4	1.5	1.4	1.5C
40	1.6	1.4	1.5	1.5	1.5BC
80	1.6	1.6	1.6	1.6	1.6BA
120	1.6	1.6	1.6	1.6	1.6A
160	1.7	1.7	1.6	1.6	1.6A
Trt. mean	1.6	1.5	1.5	1.5	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡Nitrogen rates: values indicate N applied as pounds acre^{-1}.

§Differences between main effect means followed by the same uppercase letter and between interaction means followed by the same lowercase letter are not significant at $\alpha = 0.05$.

Table A.19. Nitrogen uptake of sorghum plants in a no-till 3-year sorghum-soybean-wheat/cover crop rotation at Manhattan, KS 2017-2019.

Season N-rates‡	Cover crop treatment†				N-rate mean
	CF	DSB	DSBCC	CCMIX	
	pounds acre^{-1}				
2017					
0	157.7	159.6	101.6	109.4	132.1D§
40	192.3	172.2	141.3	160.4	166.6C
80	231.8	225.9	166.2	188.6	203.1B
120	267.4	275.2	221.9	206.4	242.7A
160	256.7	269.6	222.9	238.7	247.0A
Trt. mean	221.2A	220.5A	170.8B	180.7B	
2018					
0	238.5ebdac	143.6g	176.5efg	195.6edfcg	188.5C
40	249.7bdac	220.7ebdfcg	159.1fg	211.2ebdfcg	210.2BC
80	276.5ba	221.1ebdfc	216.2ebdfcg	160.2fg	218.5BAC
120	228.9ebdfc	272.1bac	199.2edfcg	245.1ebdac	236.4BA
160	229.6ebdfc	301.6a	192.5edfg	273.3ba	249.2A
Trt. mean	244.6A	231.8A	188.7B	217.1BA	
2019					
0	200.0	174.7	148.0	132.4	163.7B
40	184.9	177.2	144.6	161.0	166.9B
80	220.0	201.4	191.6	180.8	198.4A
120	171.5	244.7	176.2	175.1	191.8A
160	202.6	201.2	180.7	195.7	195.1A
Trt. mean	195.8A	199.8A	168.2B	169.0B	

†CF: Chemical fallow, DSB: Double crop soybeans, DSBCC: Double crop soybeans plus spring cover crop before sorghum, CCMIX: Summer cover crop mixture before sorghum.

‡Nitrogen rates: values indicate N applied as pounds acre^{-1}.

§Differences between main effect means followed by the same uppercase letter and between interaction means followed by the same lowercase letter are not significant at $\alpha = 0.05$.

Appendix B - Greenhouse gas emissions from wheat harvest through sorghum harvest

Introduction

Greenhouse Gases (GHG) are defined as any gas that captures and redistributes heat, causing an abundance of warmth on the planet (Brander, 2012). The primary GHG are water vapor, carbon dioxide (CO_2), methane (CH4), nitrous oxide (N_2O), and ozone and all have a global warming potential (GWP). Carbon dioxide is the most abundant GHG in the atmosphere and is primarily the result of human activities (Brander 2012, Overview of Greenhouse Gases, 2019). All of these gases behave differently and their attributes, such as life cycle and absorbance rate, are used to determine their GWP compared to CO_2 (Brander 2012). Though all are detrimental to the environment, N_2O will be the focus of this discussion.

Although N_2O emissions can come from multiple sources, such as transportation, industry, burning fuel, etc., the leading cause by far comes from the agricultural industry (Overview of Greenhouse Gases, 2019). Globally, N_2O represents a small percentage of all GHG (6%), though the agriculture industry is still the leading cause. The reason for the agriculture industry being the main source of N_2O emissions is largely due to N fertilizer use for optimal crop growth and yield (Omonode et al. 2011; Mitchel et al. 2013). Several processes must occur to these applied fertilizes before N_2O emission are released.

Plants take up N from the soil as either nitrate (NO3-) or ammonium (NH4+) (MacAdam 2009). Inorganic N fertilizer sources typically contain one or the other of those molecules or urea (CH_4N_2O). Urea is broken down into NH_{4+} and HCO_3^- within the soil profile by the urease enzyme produced by ammonia-oxidizing bacteria. Other microorganisms convert N contained in organic material into NH_{4+} through a process known as mineralization (Lamb et al. 2014).

Regardless of its original source, if ammonium is not utilized by the plant, it can be converted to NO_{3-} in a multi-step process known as nitrification with nitrite (NO_{2-}) as an intermediate molecule. Nitrate N can be lost of from the soil profile through a process known as denitrification (Lamb et al. 2014).

Before denitrification can take place, soil conditions must be met. Denitrification occurs when oxygen gas within the soil profile becomes limited, and bacteria use oxygen molecules from nitrate for energy reactions (Wortmann, 2006)). Bacteria utilize nitrate in this way when anaerobic conditions, within the soil profile, are met. When this takes place, N is then released from the soil profile in a gaseous form (N_2O). It is important to note that N_2O released from denitrification comes from nitrate alone.

As mentioned above each individual GHG has a different life cycle and absorbance rate. The N_2O molecule has a GWP that is roughly 300 times that of CO_2 and has a life span of over a century (Overview of Greenhouse Gases, 2019; Brander 2012). Therefore, N_2O emissions are of great concern (Baggs et al. 2003), and growers should consider management options to help mitigate these emissions.

Materials and Methods

Nitrous oxide emissions were measured using the closed static chamber method with polyvinylchloride (PVC) chambers according to the protocols by Parkin and Venterea (2010) (Fontes, 2017). Two pieces of PVC were used, one was placed into the soil (4 in) known as the anchor (12 in diameter × 6 in long) and a closed chamber (12 in diameter× 4 in long) that was placed on top of the anchor at each sample date, and had Mylar Film tape (Fontes, 2017).

Samples were gathered once a week (weather permitting) during the CC phase (2017-2018), Sorghum phase (2018) and CC after sorghum (2018-2019). Sampling was reduced to once every two weeks during cold months (November-February), though no sampling occurred in the month of December. Anchors were placed in three (CF, DSBCC, CCMIX) of the four treatments amongst all subplots. Measurements were generally gathered between 8 a.m. and 4 p.m. local time. Anchors were placed into the soil and were installed 24 hours prior to the first sampling period and remained undisturbed. Anchors were only removed from the plots to accommodate harvesting or planting operations during each season.

During sampling, emissions were gathered at four time intervals including 0, 15, 30, and 45 minutes in every subplot. At each time interval, a 30-mL syringe was used to extract a 20-mL sample and placed into a 12-mL evacuated vile equipped with a butyl rubber septum (Labco Ltd.) (Fontes, 2017). Chamber and soil temperatures were recorded on a data sheet at each time interval at three subplots. This procedure was repeated for each replication and once the final replication was concluded, all viles were sent off for further analysis. All gas samples were analyzed by chromatography (Varian 450-GC) with an electron capture detector (ECD) (standard deviation of EDC= .009 µg L-1) to quantify N2O-N (Fontes, 2017; Wilson et al., 2015).

References

Baggs, E. M., Stevenson, M., Pihlatie, M., Regar, A., Cook, H., Cadisch, G. 2003. Nitrous oxide emissions following application of Residues and Fertiliser under zero and conventional tillage. Plant and Soil 254: 361-370.

Brander, M. 2012. Greenhouse Gases, CO2, CO2e, and Carbon: What Do All These Terms Mean? Ecometrica. https://ecometrica.com/assets/GHGs-CO2-CO2e-and-Carbon-What-Do-These-Mean-v2.1.pdf

Fontes, G. 2017. Managing cover crops and nitrogen fertilizer to enhance sustainability of sorghum cropping systems in Eastern Kansas. M.S. Thesis. Kansas State University, Manhattan.

Lamb J.A., Fernandez F.G., Kraiser D.E. 2014. Understanding Nitrogen in soils. University of Minnesota Extension.

MacAdam, J.W. 2009. Structure and function of plants. Wiley-Blackwell, Ames.

Mitchell, D.C., M.J. Castellano, J.E. Sawyer, and J. Pantoja. 2013. Cover Crop Effects on Nitrous Oxide Emissions: Role of Mineralizable Carbon. Soil Science Society of America Journal 77(5): 1765–1773. doi:10.2136/sssaj2013.02.0074

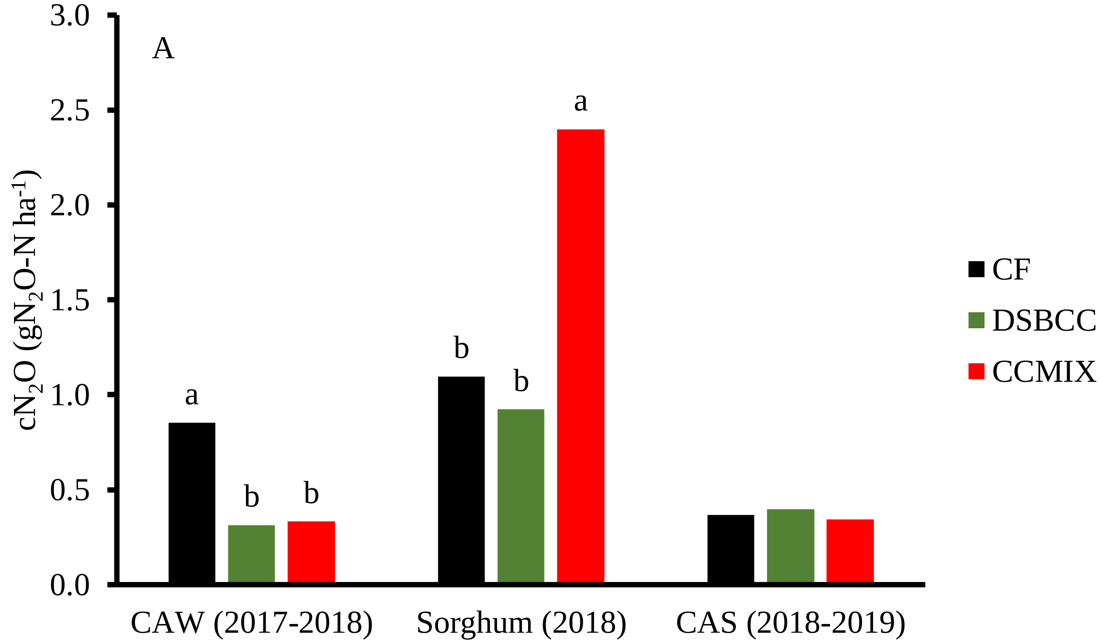
Omonode, R.A., D.R. Smith, A. Gál, and T.J. Vyn. 2011. Soil Nitrous Oxide Emissions in Corn following Three Decades of Tillage and Rotation Treatments. Soil Science Society of America Journal 75(1): 152. doi:10.2136/sssaj2009.0147

Overview of Greenhouse Gases. 2019. EPA [Online] Available at https://www.epa.gov/ghgemissions/overview-greenhouse-gases

Parkin, T.B. and R.T. Venterea. 2010. Chamber-based trace gas flux measurements. p. 3-39. In R.F. Follett (ed.) Sampling protocols. Chapter 3.

Wilson, T.M., B. McGowen, J. Mullock, D.B. Arnall, and J.G. Warren. 2015. Nitrous oxide emissions from continuous winter wheat in the southern Great Plains. Agron. J. 107:1878-1884.

Wortmann, C.S. 2006. Agricultural nitrogen management for water quality protection in the Midwest. University of Nebraska-Lincoln Extension, Lincoln, Neb.



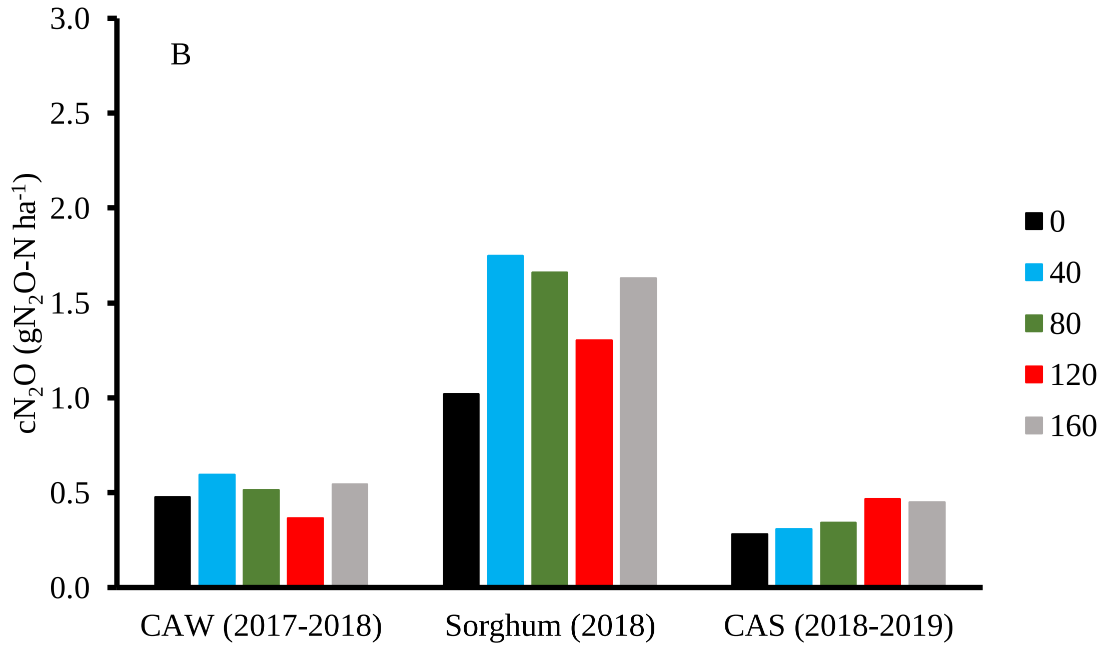


Figure B.1. Cover crop effect (A) and Nitrogen effect (B) on cumulative flux of N_2O emissions during different phases of the rotation at Manhattan, KS 2017-2019. Phases: cover crops after wheat (CAW), cover crops after sorghum (CAS). Treatments within a phase with the same letter above the bar are not significantly different (α= 0.05).

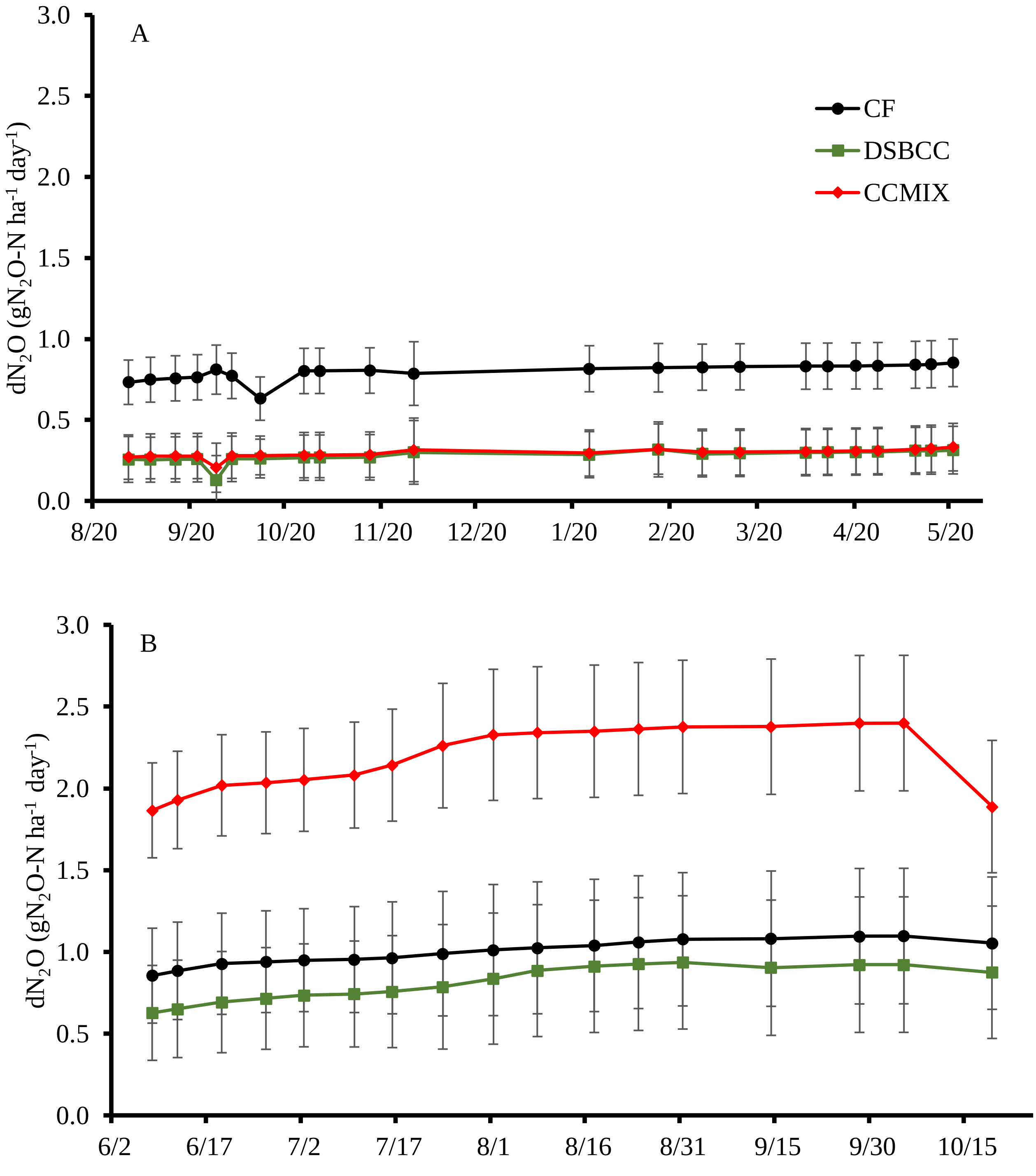


Figure B.2. Cover crop effect during fallow phase (A) and during sorghum phase (B) on daily flux N_2O emissions at Manhattan, KS 2017-2018. Treatments: chemical fallow (CF), double-crop soybean plus spring cover crop (DSBCC), summer cover crop mixture after wheat (CCMIX).

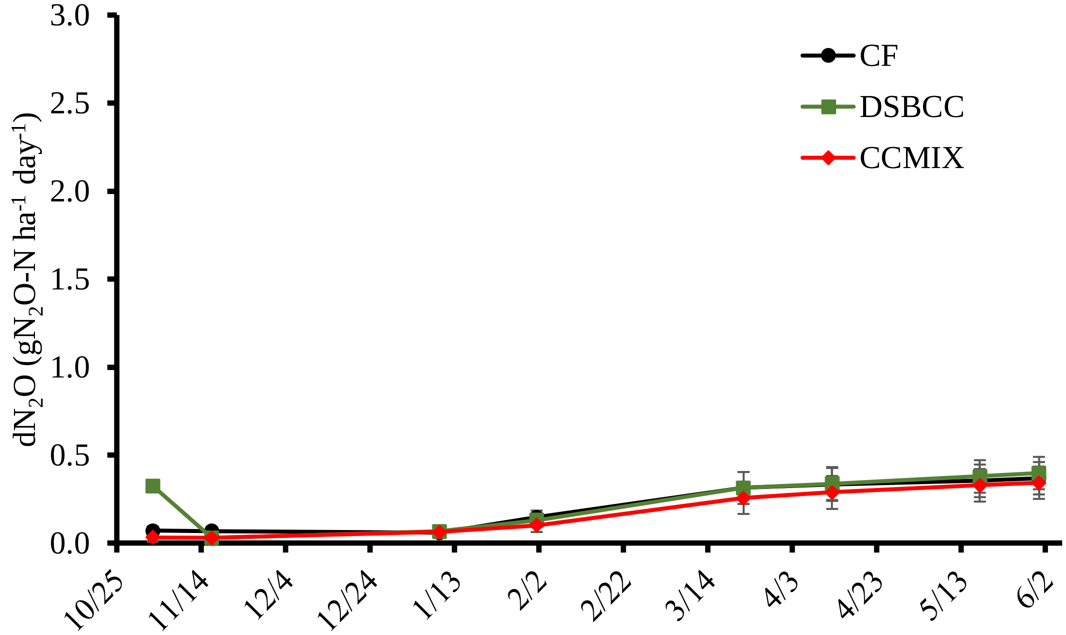


Figure B.3. Cover crop effect, after sorghum, on daily flux N_2O emissions at Manhattan, KS 2018-2019. Treatments: chemical fallow (CF), double-crop soybean plus spring cover crop (DSBCC), summer cover crop mixture after wheat (CCMIX).

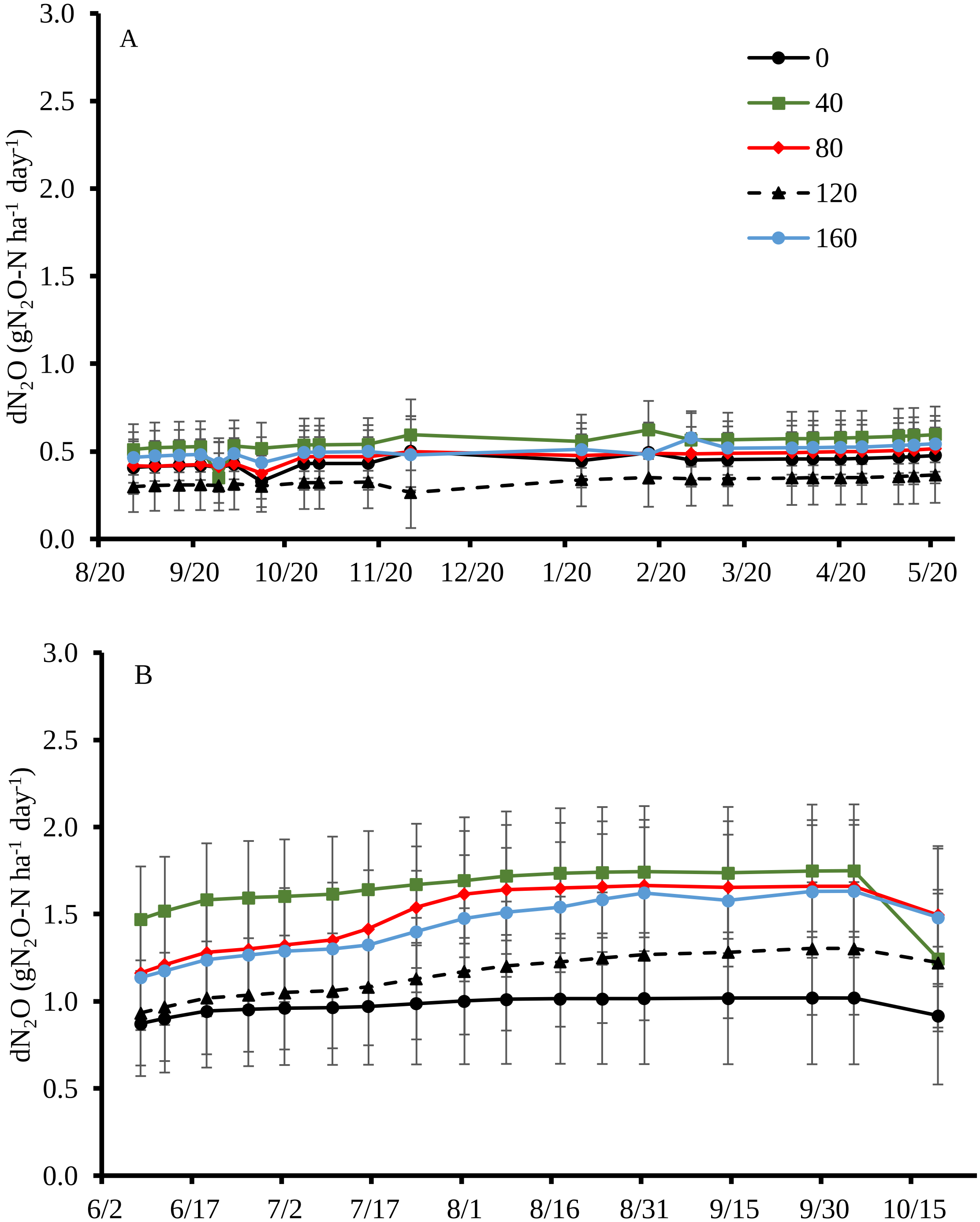


Figure B.4. Nitrogen effect, before sorghum (A) and during sorghum (B), on daily flux N_2O emissions at Manhattan, KS 2017-2018. 0 ,40, 80, 120, 160 pounds acre^{-1} of N fertilizer applied at sorghum planting.

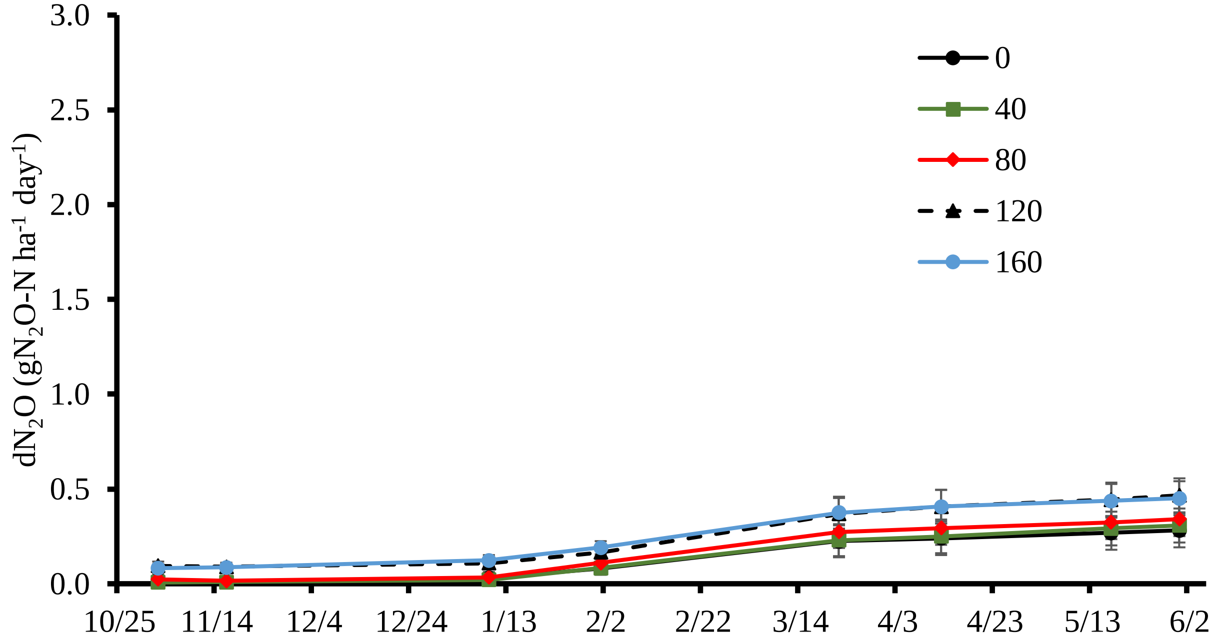


Figure B.5. Nitrogen effect, after sorghum, on daily flux N_2O emissions at Manhattan, KS 2018-2019. 0, 40, 80, 120, 160 pounds acre^{-1}of N fertilizer applied at sorghum planting.

Table B.1. Test of significance for cumulative and daily flux of N_2O emissions response to cover crop, nitrogen rate, and their interactions at Manhattan, KS 2017-2019.

Season	Source of Variation		
Date	Cover crop (CC)	Nitrogen (N)	CC×N
	——————— Probability of >F ———————		
Cumulative Flux			
CAW†	0.023	0.739	0.265
Sorghum	0.033	0.149	0.828
CAS	0.860	0.113	0.543
Daily Flux			
CAW			
2017			
Aug. 31	0.048	0.771	0.396
Sept. 7	0.044	0.750	0.326
Sept. 15	0.043	0.750	0.324
Sept. 22	0.041	0.749	0.322
Sept. 28	0.025	0.813	0.966
Oct. 3	0.039	0.748	0.317
Oct. 12	0.027	0.752	0.379
Oct. 26	0.027	0.765	0.269
Oct. 31	0.026	0.765	0.266
Nov. 16	0.027	0.765	0.260
Nov. 30	0.158	0.656	0.294
2018			
Jan. 25	0.028	0.760	0.254
Feb. 16	0.054	0.720	0.198
March 2	0.025	0.754	0.244
March 14	0.025	0.749	0.239
Apr. 4	0.024	0.752	0.242
Apr. 11	0.024	0.751	0.245
Apr. 20	0.024	0.747	0.250
Apr. 27	0.024	0.743	0.253
May 9	0.023	0.739	0.259
May 14	0.024	0.738	0.262
May 21	0.023	0.739	0.265

†CAW: Cover crops after wheat, CAS: Cover crops after sorghum.

Table B.2. Test of significance for daily flux of N_2O emissions response to cover crop, nitrogen rate, and their interactions at Manhattan, KS 2017-2019.

Season Date	Source of Variation Cover crop (CC)	 Nitrogen (N)	 CC×N
	———————— Probability of >F		————————
Daily Flux			
Sorghum			
2018			
June 8	0.014	0.329	0.665
June 12	0.018	0.328	0.701
June 19	0.012	0.329	0.750
June 26	0.012	0.333	0.740
July 2	0.013	0.326	0.730
July 10	0.015	0.304	0.714
July 16	0.020	0.258	0.699
July 24	0.029	0.194	0.682
Aug. 1	0.033	0.164	0.713
Aug. 8	0.032	0.156	0.748
Aug. 17	0.032	0.153	0.760
Aug. 24	0.032	0.147	0.771
Aug. 31	0.033	0.142	0.783
Sept. 14	0.033	0.154	0.810
Sept. 28	0.033	0.150	0.827
Oct. 5	0.033	0.149	0.828
Oct. 19	0.084	0.269	0.665
CAS†			
2018			
Nov. 2	0.508	0.010	0.377
Nov. 16	0.403	0.002	0.287
2019			
Jan. 9	0.963	0.023	0.881
Feb. 1	0.707	0.021	0.776
March 22	0.827	0.176	0.500
April 12	0.870	0.121	0.502
May 17	0.887	0.123	0.514
May 31	0.860	0.113	0.543

†CAS: Cover crops after sorghum.