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Cover Crop Establishment and Potential Benefits to Arkansas Farmers

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Cover Crop Establishment and Potential Benefits to Arkansas Farmers

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ABSTRACT

Soybean farmers in Arkansas need best management practices (BMPs) that maximize the benefits of using cover crops including planting date and fertilization recommendations. An evaluation of cover crop species, planting dates, seeding rates, fertilizer rates, and N accumulation aids in providing these BMPs. The first objective of this research is to assess the effect of planting date on biomass production, as well as looking at the interaction of seeding rate or fertilizer rate for legumes or non-legumes, respectively, using Austrian winter pea (*Pisum sativum*), cereal rye (*Secale cereale*), black oats (*Avena strigosa*), wheat (*Triticum aestivum*), and tillage radish (*Raphanus sativus*). Crops were planted on five dates in three locations across the primary crop production regions of Arkansas, using either variable Agrotain-treated urea rates or variable seeding rates. Agrotain is a N fertilizer additive that inhibits urease activity and limits ammonia volatilization loss potential. A 0.9 x 0.9 m sample of above-ground biomass was oven-dried and weighed to determine total cover crop biomass production. This research found that earlier planting dates were preferable for all species and that fertilizer or seeding rates did not have much effect on establishment and biomass across all planting dates.

The second objective was to gauge the potential N credits by assessing the N accumulation via biological N fixation of three legumes in two locations. Three species were evaluated and compared for N accumulation at termination – Austrian winter pea, hairy vetch (*Vicia villosa*) and crimson clover (*Trifolium incarnatum*). Pea biomass was taken from the above study, and pea, vetch, and clover biomasses were taken from an herbicide tolerance study. A 0.9x0.9 meter sample of above-ground biomass was oven-dried, ground, and analyzed for total N. This study found that Austrian winter pea generated more biomass on average, and accumulated the most N.

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CHAPTER 1

Introduction

INTRODUCTION

Cover crops have historically been used to improve soil health, slow erosion, conserve water, manage insect pressure, and suppress weeds. With the advent of chemical compounds to achieve those ends, cover crops fell out of favor in Arkansas. However, movements toward sustainability have brought the practice out of obscurity, and this project will help provide best management practice recommendations for farmers wishing to pursue this option. This project will look at four cover crops in three locations, at five planting dates with variable seeding and fertilizer rates, to furnish recommendations for the establishment and effective use of cover crops in Arkansas. We will also look at the nitrogen (N) recovery rates of the leguminous cover crop, as well as two other legumes, in one location. This study will provide general recommendations for establishment and N credits, and further study is warranted to assess optimal seeding rates for specific applications such as weed control or erosion reduction.

Currently, Arkansas does not have cover crop recommendations for farmers across the state. This project looks at four cover crops, one of which is leguminous while the other three are not. The goals are 1) to ascertain which planting date and fertilizer/seeding rate are the most appropriate for Arkansas farmers, 2) to provide guidance on choosing a cover crop for their needs, and 3) to calculate the N credits that may be available to them after using a legume cover crop. Cover crops are a great choice for farmers who want to improve soil organic matter, prevent erosion, and incorporate a more sustainable model into their farming operation.

HISTORY

Winter cover crops have been used, historically, to shelter and nourish the ground while it is not planted to cash crops, preventing erosion and nutrient leaching (Dabney et al., 2007; Decker, 1994; McNeil, 2004; Reeves, 1994; Tonitto et al., 2006). The benefits from cover crops have been documented in several soil types across the country, and the predominately silt loam soils of Arkansas are not an exception. Cover crops combat numerous agricultural hurdles besides erosion and leaching, such as weed pressure, insect pressure, nutrient loss, nutrient management, and healthy soil microbiology maintenance (Cassman et al., 2002; Dabney et al., 2007; Hartwig, 2002).

BROAD BENEFIT

Cover crops prevent erosion via their physical presence covering the ground. Their roots increase the water-holding capacity, soil organic matter (SOM), and cation exchange capacity (CEC) of the soil, effectively reducing nutrient leaching. A cover crop that is mowed down or even allowed to remain outcompetes weeds for available soil space and nutrients between cash crop rows, and has a similar, although mitigated, effect when tilled under. Allelopathic root exudates extend this benefit by suppressing nearby weed seedlings during their germination and prior to emergence. A cover crop that is a non-host for overwintering insects reduces insect pressure by removing the food source. Alternatively, cover crops that are hosts for beneficial insects reduce insect pest pressure by increasing the number of predatory insects that can survive in that location (Dabney et al, 2007; SARE, 2007).

Cover crops aid in nutrient cycling during their growing season by scavenging the leftover nutrients from the season previous and returning those nutrients to the soil profile upon their decomposition. Their root systems, whether fibrous or tuberous, also provide various benefits by allowing the next crop better access to deeper nutrients (SARE, 2007; Wyland, 1996). This in turn allows for better nutrient management, as the farmer can make more efficient and cost-effective fertilizer choices while reducing his or her detrimental impact to the environment (Farber, 2006). The least obvious benefit is that to the soil microbes and micro fungi, which contribute immensely to soil health. The choice of winter cover crop varies with climate, soil needs, weed pressure, insect pressure, and cost (Fageria et al., 2005; Kuo, 2000). Cover crops may be leguminous or non-leguminous, and specialize in different attributes.

ARKANSAS

Most of Arkansas, excluding the mountainous northwest corner, falls in winter hardiness zones 7 and 8, which have milder winters and make growing winter cover crops an easier task (USDA and OSU, 2012). Cover crops can serve a variety of purposes depending on the needs of the farmer and soil in question (Reeves, 1994). Current recommendations are lacking for this region, however, as most of the research has been done in the northeastern United States and in California (Snapp, 2005). Farmers in Arkansas will have different needs depending on their crop rotation and specific soil texture. If the desired next rotation is soybean (G*lycine max,)* the desired characteristics of the preceding cover crop will be different from corn *(Zea mays*). For example, a legume cover crop may be chosen preceding corn due to corn's high N requirements, whereas if the cover is preceding soybean, the added N may not make as much difference and there is an increased risk of pest and disease carryover.

Arkansas farmers often have the additional consideration of economic depression or low commodity prices. Using an inexpensive cover crop that recaptures some of the fertilizer that has already been bought, and lessens the need for irrigation on the cash crop by retaining soil moisture and improving water infiltration, may prove to be the most cost-effective solution for financially burdened farmers in the south (O'Reilly, 2011). A USDA program called the Environmental Quality Incentives Program, or EQIP, allows farmers to apply for federal financial and technical assistance to develop conservation practices and to comply with environmental regulations. Cover crops are one of the recognized methods for environmental improvement. Use of this program further alleviates financial pressures on Arkansas farmers (USDA, 2016). The program covers the cost of specific seed types or seed blends, as well as covering the cost of termination. Currently, the highest rate available to most famers utilizing this program is $383.96/acre; however, farmers should be advised to consult their local USDA Service Center to ensure proper compensation.

SOYBEAN

Soybean is the second largest crop in production in the United States after corn. In 2014, 108 million tonnes of soybeans were produced in the United States on a total of 33.6 million hectares (USDA, 2015), which equates to an average of 3.2 tonnes per hectare. Soybean is one of Arkansas's leading crops, with Arkansas ranking 10th in the country in soybean production. With production reaching about 140 million bushels per annum, growing soybeans efficiently is a notable concern for farmers in this state. Further, soybean is only growing in popularity for consumers and industry alike as technology advances and cultural preferences change. Vegetarian and vegan food options, which are gaining in popularity in the United States, often rely on soy protein and soybean oil since soybean is about 18% protein and 38% oil. An astonishing number of products can be made from soybean, including animal feed, biofuel, particleboard, carpet and upholstery backing, industrial solvents and lubricants, foam, candles, crayons, and printer ink (NCSPA, 2016). The diversity of available soy products only emphasizes the growing need to understand the best methods for production.

Soybeans have atypical requirements for their growing season compared to other cash crops (Drinkwater, 2000). As a legume, soybean fixes its own N from the air, and therefore has very different fertilization requirements than other major cash crops such as corn, rice (*Oryza sativa*), and cotton (*Gossypium hirsutum*.) Soybean breeding and genetic research is crucial to efficient production, but researching the external variables that influence yield may provide key insights to maximizing production and minimizing cost and potential negative environmental impacts. Examining the benefits of cover crops to legume cash crops is an under researched topic, given that much of the research focuses on corn succession.

SOIL QUALITY

Soils in Arkansas are typically lower fertility and lower quality than soils found in the midwestern United States and upper northeastern United States, where considerable research on cover crops has been done. This could potentially produce an even greater benefit from cover crops, as the increased yield further aids the farmers to maximize production and reduce input costs such as fertilizer, irrigation, herbicides, and pesticides. Aside from the immediate financial benefits, the long-term benefits to the soil are increased water holding capacity, increased soil organic matter, and increased CEC (Drewry and Paton, 2005; Ketterings, 2015). Improving the soil quality over the years is advantageous both for the farmer who owns the land and for the farmer who leases the land. Many landowners who lease their farms are willing to adopt a low-cost strategy for long-term benefits. Different strategies may be employed depending on the condition of the land, the landowner's preferences, the farmer's preferences, and the primary cash crops grown (Snapp, 2005). A farmer who rotates soybean and corn is likely to have far different cover crop needs than a rice farmer or a farmer who grows continuous cotton, and a farmer on sandy soil may need more rotations to see an improvement than a farmer on silt loam or clayey soil.

Weed Control

Farmers are always looking for an efficient method for weed control. Cover crops have been used to reduce weed pressure via two methods: physical suppression due to smothering and chemical suppression due to allelopathic chemicals in the roots and residue (Creamer, 1996; Dabney et al., 2007; Lawley, 2012; O'Reilly, 2011). This suppression improves yield even if weeds come up later in the season (SARE, 2007). Interestingly, many or most studies do not assess seeding rates attempting to suppress range of weeds, but rather take the approach that one seeding rate is sufficient to determine whether a certain crop suppresses a certain weed, as shown in Creamer et al (Creamer, 1996).

This approach is not entirely without merit. Weed suppression can be less straightforward than it seems; if the cover crops themselves prove difficult to kill, they effectively become weeds themselves. Additionally, if the chemical effects that disrupted weed growth linger in the soil, they can affect the cash crop, rendering weed suppression inadequate as a reason for cover crop usage. Timing the end of the cover crop, through mowing, burndown, or tillage, is a critical step in ensuring the best result from the cover crop and the best performance from the cash crop. If planted too early, some beneficial effects may not be seen. If planted too late, in addition to the cover crops becoming weedy, the allelopathic effects may damage the cash crop.

Pest Control

Pests are typically defined as organisms which negatively affect the growth or reproduction of the desired crop (Abivardi, 2008). Insect pest control is as important as, if not more important than, weed control for quality grain yield of the succeeding cash crop. Not only do they damage the plant physically by eating or laying eggs in it, insects such as aphids also are vectors for a wide range of diseases that can be transferred via feeding methods or excrement (Blackman and Eastop, 1984). Insect management is complex and must consider beneficial as well as pest insects. Insects such as parasitoids, predators, and pollinators are valuable contributors to the overall health of the field (SARE, 2007). Beneficial insects are beginning to receive more recognition for their role in reducing pest populations in an environmentally friendly manner, a process known as biological control or biocontrol.

There are several insects regarded as beneficial to farmers. Insidious flower bug (*Orius insidiosus*) is a type of minute pirate bug, a member of the Anthocorid family, which feeds on the eggs of corn earworm (Kiman, 1985). Common earwig (*Forficula auricularia*) is omnivorous and predatory to a range of arthropods (Brindley, 1918). Parasitoid wasps such as those in the Braconid family are a popular and effective biocontrol measure against egg-laying insects (Wharton, 1997). Cover crops are often hosts for such beneficial insects (Landis, 2000). An economic advantage to nurturing populations of beneficial insects on the cover crops is that cover crop seed is much more cost effective than pesticides, and there is no risk that pest insects will develop a resistance to being eaten, unlike the risk that they will develop a resistance to pesticides.

Due to the mild climate in the mid-south relative to much of the country, terminating cover crops at an appropriate interval before planting cash crops is an important consideration in influencing insect pest populations. A gap in the food source helps reduce the populations of pests that overwinter as adults by breaking the “green bridge” on which the insects survive from one crop to the next. Proper pest management depends greatly on the main pest being targeted. If the cover crop is a host for insect pests, mowing the cover crop early is the best way to partially exterminate the pest (Wyland, 1996). With proper termination, cover crops can also be used as "trap crops" to lure in the insect pests and destroy them before they can mature and reproduce. Bollworm, for example, will fail to pupate if the cover crop in which it has survived the winter is terminated prior to approximately May 10 in New York (Dabney et al., 2007).

Thoughtfully rotating the cover crop used as well as keeping the succeeding or bookending cash crops in mind will assist in breaking the "bridge" or food source for a specific pest, whereas a poor rotation choice could worsen insect pest pressure. For example, planting a legume cover crop prior to cotton is inadvisable because of the likelihood for tarnished plant bug (*Lygus lineolaris*) to maintain populations above the economic threshold and become a major pest for cotton that year (Dabney et al., 2007). Conversely, chinch bug (*Blissus leucopteris*), a major pest of grass crops such as corn , may be controlled by planting a legume cover crop because chinch bugs feed primarily on grasses, and so the adults overwintering in the field will starve (NCSU, 2016; Reeves, 1994; SARE, 2007). Keeping these variables in mind when choosing a cover crop is an important consideration for the success of the following cash crop.

In addition to insect pests, pathogens such as *Sclerotinia minor* may also become a problem with cover crops (Dabney et al., 2007; Koike, 1996). *S. minor* is a fungal pathogen that causes wilting and rotting of the plant and, although not considered a major problem, has a very broad host range including economically important plants (Jagger, 1920; Melzer et al., 1997). Once those problems are addressed, however, cover crops can be a valuable tool for weed suppression (Creamer, 1996; O'Reilly, 2011; Reeves, 1994).

Erosion

Nearly all cover crops reduce soil erosion and leaching simply due to their root systems and the ground covering nature of the biomass (Decker, 1994; Reeves, 1994). They also keep the soil warmer in cool, wet conditions, meaning that the typically cool, wet winters in Arkansas are prime for cover crop implementation. Cover crops have been shown to reduce the amount of erosion as calculated by the Universal Soil Loss Equation (USLE.) A study by Langdale in 1991 showed less erosion, whether conventionally tilled or no-till, compared to fallow. A variety of cover crops were tested between cash crops of corn, soybean, and/or cotton (Langdale, 1991). Although a minimum rate of cover crop seeding has not been established, a cover crop that has established at least 40% soil cover by the beginning of winter can provide "substantial" protection from erosion (SARE, 2007). The specific range of biomass necessary to effect significant reduction in erosion is a subject for further study.

Cover crops also improve the water infiltration rate and reduce the erosion occurring through runoff (Dabney et al., 2007; Fageria et al., 2005; Langdale, 1991; Ketterings, 2015; SARE, 2007; Wyland, 1996). A deeply rooted cover crop may help break up compacted soil, and, in doing so, will also increase the water holding capacity of that soil (Chen, 2009). Therefore, there will be a) less runoff, and b) fewer nutrients lost in the runoff (Dabney et al., 2007; Rosolem, 2001; Villamil et al., 2006; Williams, 2004). The increased soil organic matter is effectual in water retention as well as soil aggregate stabilization, and the resulting higher CEC plays a part in preserving nutrients in the soil that have not already been immobilized (Fageria et al., 2005).

Leaching

The effect of cover crops on leaching is similar to their effect on erosion – they reduce the loss of water and nutrients by physically retaining them and by allowing the soil to retain them (Ketterings, 2015). They also allow cash crops to penetrate further into the soil profile, making some nutrients that had leached below the former root zone accessible once again. Cover crops like radish (*Raphanus sativus*) can alleviate soil compaction by breaking up the soil deep into the profile with their taproots. Both the disturbed soil profile and the nutrient-storing cover crop roots allows the cash crops better access to nutrients that would otherwise be too deep in the soil to reach. Retaining the nutrients in the soil over the years further allows the farmer to reduce the amount of applied fertilizer, reducing the amount lost to leaching (Brennan, 2012). Reduced leaching loss is beneficial both economically and environmentally because it prevents wasted money for fertilizer and prevents pollution of waterways and groundwater at the same time.

CATCH CROPS AND FERTILIZER

Cover crops contribute to nutrient cycling and nutrient management, scavenging N (and other nutrients) from the soil and holding it in the biomass until decomposition, fixing N from the air, or both (Aronsson, 1998; Reeves, 1994). Scavenged N is converted into proteins, making cover crops a good choice for livestock forage (Dabney et al., 2007; Rosolem, 2001). Cereal rye (*Secale cereale*) and radish each have very fast root growth, making them excellent nutrient scavengers (Dabney et al., 2007; SARE, 2007). Legumes like peas (*Pisum sativum*), clover (*Trifolium incarnatum*) and hairy vetch (*Vicia villosa villosa*) contribute to the N in the soil profile by fixing it from the atmosphere. Black oats (*Avena strigosa*) are a more succulent alternative to cereal rye, meaning that they decompose more quickly. This allows them to release their scavenged nutrients back to the soil more quickly than the tougher, more fibrous cereal rye stalks.

Regardless of the method that a cover crop utilizes for nutrient scavenging and retention, the focus with cover crops is on the eventual cycling of soil nutrients with a minimum of loss. Nutrient cycling is an important part of sustainable farm management (Cassman et al., 2002; Fageria et al., 2005; Kuo, 2000; Tonitto et al., 2006) because it allows the farmer to efficiently plan his or her fertilization requirements and minimize losses that would damage the environment or subtract from the economic benefit of application (Pantoja, 2010). It is important in an economically repressed community to stress the benefits that cover crops can bring both for the community and for the individual. Improving soil health and nutrient cycling positively impacts both.

LEGUMES

A leguminous cover crop will fix N in the soil for subsequent crop use which could be used in a longer rotation such as corn>hairy vetch>soybean>field pea to build up the soil N for the corn's use at the start of the next rotation (Fageria et al., 2005; Villamil et al., 2006). This N fixation occurs through a symbiotic process with bacteria that form nodes on the roots. The amount of N fixed or immobilized by a legume cover crop can give "N credits." Although it is impossible to ascertain precisely whether the N in the soil was from the legume or from other sources, it remains evident that the amount of N fertilizer needed for subsequent cash crops changes as legume N accumulation changes (Ebelhar, 1984, O'Leary, 2013).

Legumes are also excellent forage for cattle, allowing legumes to serve dual purposes for small farmers with both cash crops and livestock (Decker, 1994; Drinkwater, 1996; SARE, 2007). The nutritional quality of legumes as forage is excellent because they are high in crude protein and mineral content (Uzun et al., 2005). Legumes grown for their seed may see a benefit to reduced biomass production because the plants will not strangle each other due to their sprawling growth habit (Cousin, 1997). In general, the benefit to adding a legume to the yearly cropping rotation is that not only does the leguminous cover crop scavenge nutrients in the soil both from native fertility and from leftover fertilizer, but it also fixes additional quantities of atmospheric N. Lastly, tender legume cover crops are more likely to winterkill, potentially saving the farmer the diesel and labor necessary to apply the chemical termination.

Non-Legumes

Non-leguminous cover crops, mainly cereals, can have a variety of benefits depending on their structural makeup, chemical composition, and hardiness. Crops with a large amount of biomass and a fibrous root system can outcompete and suppress weeds, improve infiltration, reduce erosion, and potentially harbor beneficial insects. Crops with a tuberous root system and more delicate aerial biomass can substitute as tillage (Chen, 2009), and some studies have found that crops with these qualities in the genus *Brassica* have superior nutritional quality as cattle forage. Cereal rye and oats are cereals that aid primarily in weed suppression and erosion prevention, whereas tillage radish, also known as forage radish, is an example of a Brassica that breaks up compacted soils and provides nutritious forage. Non-leguminous crops are better scavengers of nutrients but do not fix their own nutrients from the atmosphere using symbiotic bacteria like legumes do (Brennan, 2012).

Microbiology

Beneficial soil microorganisms and mycorrhizae are a bonus feature of cover crops that are often overlooked. Microorganisms contribute to soil health in terms of soil structure, decomposition, nutrient cycling, and disease prevention (Garbeva et al., 2004). Soil aggregate size is a key factor in microbial activity (Mendes, 1998), and the "tillage" of the soil accomplished by cover crop roots may play a beneficial role. Additionally, cover crops are generally shown to increase the microbial community more than mineral fertilizer. This is thought to be largely to the additional carbon that the soil receives from decomposed and tilled-in cover crops (Gunapala, 1997).

The symbiotic nature of plants and the microbial community is exemplified by the benefits to both plants and microbes. Which microbes are in the rhizosphere will depend on the root exudates, which in turn impacts the extent of benefit to the plant (Garbeva et al., 2004). Microbes also take their nutrients from the soil solution, sequestering the nutrients until the end of their life cycles, at which point they are returned to the soil for plant use as the organism decomposes. An example of this cycle is immobilization and mineralization of N. Since a healthy microbial community can immobilize fertilizer nutrients, ensuring a healthy population could potentially decrease fertilizer requirements the following year, provided that the community is not so abundant that it begins outcompeting and stealing nutrients from the roots (Buyer, 1998).

Along with microbes, there are other microscopic benefactors to the soil such as micro fungi, or mycorrhizae. Mycorrhizae benefit the cash crops by symbiotically allowing the roots to absorb more water and nutrients via extraradical hyphae. If the cover crops are not terminated too early in the season, the cover crops that host mycorrhizae, specifically vesicular arbuscular mycorrhizae, can increase the amount of mycorrhizal inocula in the soil for the succeeding crop by maintaining a relationship with the fungi. A specific protein produced by mycorrhizae called *glomalin* is beneficial not only to the plant directly but also to the soil aggregate stability (Dabney et al., 2007; Kabir, 2002). Oats and rye as winter cover crops have been shown to increase the mycorrhizal inoculum and improve soil aggregate structure over fallow. Both covers showed significant improvement in the density of soil mycorrhizal hyphae and in phosphorus uptake, a result of the vesicular arbuscular mycorrhizal colonization. Soil aggregate stability also showed significant improvement using either cover crop (Kabir, 2002). Mycorrhizae form an important ally for plant health and should be regarded as a motivating factor for cover crop usage.

Rye

Cereal rye is a winter cover crop used for its cold hardiness. It is an introduced species which can grow throughout the US and Canada. It is an excellent nutrient scavenger, preventing the loss of N from the soil profile through leaching or denitrification and retaining a spectrum of other nutrients. Its widespread root system and abundant fibrous biomass reduce soil erosion and suppress weed growth (Duiker, 2004). Rye is a good choice for the winter before legume crops, but not as much for cereal crops such as corn, because it is a host for the pests of cereal crops. It controls broadleaf seedlings both physically, by smothering, and allelopathically when residues are left in the field. Rye puts on biomass quickly and is well-adapted to a variety of soils and climates. It is a versatile choice with many benefits (Pantoja, 2010). Its biggest drawback is that it may immobilize N and other nutrients because it decomposes slowly and may not release the nutrients in time to be of use to the cash crop. (Creamer, 1996; USDA, 2016; SARE, 2007)

Detriments to using cereal rye are similar in description to the benefits – it puts on a large amount of biomass quickly. It can be hard to kill, meaning that rye may become a weed in cash crops or prevent seedling emergence due to smothering, especially in low- or no-till situations, although it has been used successfully prior to corn in no-till fields for significant weed suppression over the growing season (Duiker, 2004). Cereal rye also decomposes slowly, which means that the nutrients scavenged over the winter may be tied up in its biomass and not available for use by the cash crop.

Black Oats

Black oats are a low-cost grain cover that produces ample biomass and catches N, phosphorus, and potassium. They are easy to establish and often winter kill, which means that they do not need to be sprayed or tilled in the spring, although that can vary with the variety of oat and the severity of the winter. Like rye, they can both smother weeds and suppress them chemically with allelopathic compounds in the residue. They are often planted as a mix, although this project focuses on the cover by itself. Although the soil benefits from leaving the residue in the field, there are also the options to graze or hay the oats, or to harvest the oats themselves for human consumption (Ashford, 2003; Bayer, 2000).

The detriment to planting oats is that they are relatively easy to kill, although they may make up for that by providing forage or additional income. They also outcompete other plants relatively easily, which is good when seeding a monoculture, but detrimental when planted as a mix, as oats often are (Ashford, 2003; Caballero, 1995) However, as a whole, oats have little to distinguish themselves as a problem crop (SARE, 2007).

Radish

Radish is also known as “tillage radish” due to the greater soil disturbance made by the bulky taproot. Radish puts on biomass quickly and is a great nutrient scavenger due to the penetrative depth of the roots. The biomass successfully outcompetes fall weeds even if the residues decay very quickly or are removed (Lawley, 2012). An important contribution of radish is their natural pesticidal properties, although the efficacy is low compared to commercial pesticides. Radish has also been used with some success to prevent plant diseases and as a trap crop to reduce nematode populations. For farms with livestock as well as cash crops, radish makes a preferential and nutritious forage for cattle (Wiedenhoeft, 1994) although care must be taken to not overcrowd the cattle and contribute to soil compaction despite the radish taproots (Drewry and Paton, 2005).

Radish often winterkills, but can survive a mild winter especially if it exhibited poor fall growth. Poor growing conditions in the fall or a late planting date may necessitate the use of glyphosate, paraquat, or similar herbicide, or mowing if a green manure is preferred. This cover is compatible with a range of soil pH and soil types but prefers well-drained soil. (USDA, 2016; SARE, 2007) Because of that, radish may be a non-intuitive choice in many parts of Arkansas because of the poorly-drained soils, which occur throughout the state regardless of soil texture. (Francis, 2014.)

The primary benefit of tillage radish is the alleviation of soil compaction, which allows much greater water infiltration and cash crop root penetration for nutrient absorption (Gruver, 2015). However, radish does not always penetrate a hard pan, which can be a good thing if the following crop is rice or detrimental if the following crop needs greater root penetration.

WHEAT

Wheat can be planted as a cover crop rather than a cash crop for a variety of reasons. As a small grain cereal, wheat has a high carbon to nitrogen (C:N) ratio, which provides soil organic matter that takes time to decompose. Its fibrous root system aids in erosion reduction, water infiltration and retention, and nutrient scavenging. Wheat roots are also preferred hosts for vesicular-arbuscular mycorrhizae (VAM), which are symbiotic fungi that assist plants in their uptake of water and nutrients in exchange for sugars (Boswell, 1998, Dabney et al., 2007). Wheat cover crops provide a winter host for the mycorrhizae, allowing them to survive until their next relationship with summer cash crops. It can also be cheaper and easier to manage than rye, and farmers have the option to harvest it for the grain as a cash crop instead of leaving it all for cover, making it a popular choice (SARE, 2007).

Among the few drawbacks to planting wheat is the necessity to wait to plant until the Hessian fly-free date to avoid damage by and perpetuation of this pest. Hessian fly (*Mayetiola destructor*) is a common pest of wheat and can be managed by planting a little later in the fall and using resistant wheat varieties. In general, wheat is a good all-around choice because of its adequate weed suppression, erosion control, lack of aggressive growth, and possibility for additional income (Briggle, 1987; Tooker, 2012; SARE, 2007).

PEAS

Austrian winter pea is also known as "field pea" and is a leguminous cover crop, which fixes high quantities of N and decomposes quickly after dying (Cousin, 1997). It is very water-efficient in its biomass production compared with other legumes. Field peas are beginning to be in demand as forage and for human consumption (SARE, 2007). Early flowering supports local pollinators, and the vines are likely to make it through the winter despite being more succulent than the non-legume covers in this project.

The downsides to peas are that they are more susceptible to disease, nematode infestation, and higher pest populations than non-legume covers (USDA, 2016; SARE, 2007). They are susceptible to fungi, viruses, and bacteria, such as powdery milder, downy mildew, root rot, pea common mosaic, pea seed-borne mosaic, top yellow, pea enation mosaic, and *Pseudomonas*; however, Austrian winter peas are more resistant to blight than other kinds of peas (Cousin, 1997).

Insect pest carryover in legumes includes various Lepidopteran and Hemipteran pests such as increased cutworm populations (*Agrotis* and *Peridroma* spp.), tarnished plant bug (*Lygus lineolaris*), corn earworm (*Helicoverpa zea*), and tobacco budworm (*Heliothis virescens F.*). Legume cover crops are also hosts for non-legume pests, such as many of the major cotton pests (Dabney et al., 2007; Delgado, et al., 2007). Legumes in general are susceptible to plant-parasitic nematodes such as Root-Knot Nematode (*Meloidogyne incognita, M. hapla*) and Soybean Cyst Nematode (*Heterodera glycines*), so that susceptibility must be taken into consideration as well when planning a subsequent soybean crop (Trudgill, 2001).

HAIRY VETCH

Also known as Roth winter vetch or woolly vetch, hairy vetch is a legume which was introduced to almost all North America and thrives in most locations. It is cold-tolerant and is a vigorous and sprawling grower, considered a weed in some areas. Vetch should be inoculated prior to planting for best results if planted on a soil that has not previously been planted to it. Vetch is an excellent N fixer and requires sufficient phosphate for best results, although it does not show a significant response to N rates (Utomo, 1990). Like other legumes, vetch is rich in protein and minerals, and can be used as forage. It has a typical crude protein content of 16.4-17.9% on neutral pH soils. Grazing rather than harvesting also mitigates problems in monoculture harvest such as lodging, which can be an issue due to the sprawling growth habit (Frame, 2016).

Vetch is susceptible to several pests, which can be either beneficial or detrimental depending on which pest populates the area. Vetch bruchid, *Bruchus brachialis*, damages the seed and reduces the chance that vetch will reseed and become a weed for the field, which can be beneficial for the farmers who want to use it as a cover crop. However, vetch is also a host for pea aphid (*Acyrthosiphon pisum*), corn earworm (*Heliothis zea*), fall armyworm (*Spodoptera frugiperda*), and spider mite (*Tetranychus spp.*), which could damage subsequent cash crops. Timely removal helps mitigate the populations of those pests (Frame, 2016; USDA, 2016).

CRIMSON CLOVER

Crimson clover is an introduced, but now common, legume that grows well in most of the US and parts of Canada. A distinctive trait of crimson clover is that it can be frost-seeded, which is to broadcast the seed over frozen ground and let the freeze/thaw cycles take care of incorporating it (Digiuseppe, 2016). Clover, like vetch, should be inoculated with rhizobium on soils that have not previously been planted to either clover or hay. As a legume, minimal fertilization regimes for this cover crop should be maintained. Nitrogen fertilizer may be harmful to a clover stand, but sufficient phosphorus should be maintained.

Unlike other legumes, clover should be grazed minimally and with care if grazing is utilized. Close grazing during the winter will greatly affect the stand by spring, which can be detrimental if using for a green manure. Also, the risk of bloating on a stand of pure clover is much higher than if mixed with grasses, and animals should be introduced gradually. Clover used as a green manure should be plowed under 2-3 weeks before planting the cash crop (USDA, 2016).

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CHAPTER 2

Effects of Planting Date, Seeding Rate and Fertilization Rate on Cover Crop Biomass Production and Soybean Yield

ABSTRACT

Planting dates and their interactions with cover crop species, seeding rates, and fertilizer rates, are vital components for best management practices (BMPs) for farmers in Arkansas. The University of Arkansas Cooperative Extension Service seeks to provide recommendations for BMPs for a range of cover crops, depending on the farmer's need. Cover crop BMPs are under-researched due to a lengthy period of disinterest following the advent of chemical alternatives. In this study, the cover crops of interest were cereal rye (*Secale cereale*), black oats (*Avena strigosa*), wheat (*Triticum aestivum*), tillage radish (*Raphanus sativus*), and Austrian winter pea (*Pisum sativum*) planted on five dates, in two growing seasons, 2014-2015 and 2015-2016. Non-legume crops, which were the cereal rye, black oats, wheat, and radish, additionally tested the effect of varying fertilizer rates, while the legume crop, peas, tested the effect of varying seeding rates. Experimental plots at three locations across the primary row-crop producing regions of Arkansas with typical silt loam soils were used to develop statewide recommendations. Treatments included planting date, a control fertilizer rate of 0 kg N ha^{-1}, additional fertilizer rates of 34 kg N ha^{-1}, 67 kg N ha^{-1}, and 100 kg N ha^{-1}, or seeding rates of 80.7, 60.3, 40.4, and 20.5 kg ha^{-1}. Each plot was sampled in 0.9 x 0.9 meter sections for aboveground biomass, which was oven-dried at 50º C for 2 weeks. Overall, earlier planting dates significantly increased both the biomass production of the cover crops and the resultant soybean (*Glycine max.* L.) yield performance, increasing biomass by 1-4,000 kg ha^{-1} and increasing yield from 0-2,500 kg ha^{-1}. Fertilizer rates and seeding rates had limited and sporadic impact on both biomass and yield.

INTRODUCTION

Soybeans (*Glycine max* L.) are a major constituent of the agricultural economy in Arkansas. Farmers in this state currently produce around 3.8 million tonnes of soybeans every year. Around 1.3 million hectares of soybeans were planted each year in Arkansas in 2012, 2013, and 2014 (USDA, 2015). Industrial uses as well as feed and seed share the market with human consumption of soybean, which is continually growing. Arkansas farmers who grow rice (*Oryza sativa*) will commonly rotate with soybean, an efficient rotation considering that the 19 cm wide drill used for rice planting can also be used for soybean (NCSPA), and further that soybean, as a legume, provides its own nitrogen (N), thus leaving additional N in the soil upon decomposition. This can be encouraged by leaving the soybean residue in the field rather than transporting or burning it.

Cover crops have the potential to aid soybean farmers in their pursuit of yield and sustainability. Depending on the crop chosen, the farmer may experience better soil tilth, improved water infiltration and retention, improved weed and insect control, reduced erosion, a healthier soil microbe community, and reduced need for chemical fertilizer (Dabney et al., 2007; Reeves, 1994; Snapp, 2005; SARE, 2007). The federal government recognizes the importance of cover crops and has initiated a support program for farmers who choose cover crops, called the Environmental Quality Incentives Program (EQIP) (USDA, 2016). The cover crops in this study are supported by EQIP within the state of Arkansas (USDA, 2016).

Planting dates play a major role in determining cover crop selection, and the harvest date of the previous cash crop largely determines the available planting dates. Cover crop BMPs can vary based on the harvest date of the previous crop, which cover crop species is selected, the desired benefit, and growing conditions. Some cover crop species require early planting dates for fall growth, whereas some species focus on spring growth and can therefore be planted later. Fall or spring growth is further impacted by seeding rate, if a leguminous cover crop was chosen, or fertilizer rate, if a non-leguminous cover crop was chosen. The choice of cover crop largely depends on available planting date and desired benefit. For example, rye is chosen for copious quantities of biomass production as well as the ability to establish well with a later planting date, while peas may be chosen if an earlier planting date is available and nutrient fixation/retention is the desired result (Cousin, 1997; Duiker, 2004; USDA, 2016)

When assessing cover crops one must remember that the term “cover crops” refers to a wide range of plant species, which interact with a spectrum of growing conditions. A comprehensive review of all available options for Arkansas soybean farmers is ideal, but will take time to complete. The cover crops chosen for this study represent some of the more popular choices, coupled with a range of date and rate interactions to narrow down the BMPs for these plant species.

MATERIALS AND METHODS

Six small plot trials were conducted on experiment stations from 2014-2016. Sites were selected to provide representative soil textures and crop rotations as well as environmental conditions for the state of Arkansas. Plots were 1.8 m by 6.1 m, and used 19 cm row spacing. This project looked at the effect of planting date and the interaction of seeding rate or fertilizer rate for legumes or non-legumes, respectively, utilizing Austrian winter pea (*Pisum sativum*), cereal rye (*Secale cereale*), tillage radish (*Raphanus sativus*), and winter wheat (*Triticum aestivum*) in 2014 and black oats (*Avena strigosa*) in 2015. Experimental plots spanned the state: first, the Vegetable Sub-Station (VSS) near Kibler, AR, on a Roxanna silt loam soil, which is coarse-silty, mixed, superactive, nonacid, thermic Typic Udifluvents; second, the Rohwer Research Station (RRS) near Rohwer, AR, on a Hebert silt loam soil, which is fine-silty, mixed, active, thermic Aeric Epiaqualfs; and third, the Pine Tree Research Station (PTRS) near Pine Tree, AR, in a Calloway silt loam soil, which is fine-silty, mixed, active, thermic Aquic Fraglossudalfs. The crops were planted on September 15, October 1, October 15, November 1, and November 15. The non-leguminous species had four treatments of Agrotain-treated urea applied at rates at 0 kg N ha^{-1}, 34 kg N ha^{-1}, 67 kg N ha^{-1}, and 100 kg N ha^{-1} at emergence, and the legume species had four treatments of seeding rates at 80.7, 60.3, 40.4, and 20.5 kg ha^{-1}. Agrotain is a N fertilizer additive that inhibits urease activity and reduces ammonia volatilization loss potential. The experimental design was a 5 x 4 factorial design with planting date and fertilizer/seeding rate as the factors, with each location and cover crop combination analyzed separately. Experiment was not blocked by year because the plots were moved to different sites within the location for each year, due to the summer soybean crop still standing on the plot from the year previous. Rainfall and temperature were evaluated for the location effect and can be found in Tables 2.1 and 2.2.

TOTAL ABOVE-GROUND BIOMASS

Aboveground biomass samples were taken in the spring from 0.9 m x 0.9 m areas of each experimental unit at each of the locations. Sample timing was constrained by spring rainstorms, but was generally attempted 2-3 weeks before the summer cash crop was due to be planted and immediately prior to chemical termination. Fall planting dates affected the growth stages of the samples, with earlier planting dates tending to be closer to maturity. The samples were oven-dried at 50º C until a constant weight was reached and then weighed. The total above ground biomass was determined by extrapolating the weight from the sampled area and converted to kg biomass ha^{-1} (Catchpole, 1992).

Soybean Response and Statistical Analysis

Two weeks following cover crop termination via chemical burndown (glyphosate and paraquat) on April 1st, 2014, soybean was no-till drilled into the cover crop residue at a seeding rate of 390,000 seeds ha^{-1}. The soybean were grown using University of Arkansas Cooperative Extension Service guidelines for pest and overall management (Ross, 2016). The soybean at the PTRS and RRS locations were furrow-irrigated as needed to not exceed a 5-cm water deficit. Soybean yield was determined using a small-plot combine and harvesting the four bordered rows from the center of each plot and adjusted to 13% moisture content. The soybean yield design was completely randomized with cover crop biomass as the only factor, analyzed separately by location. Soybean yield response at PTRS and RRS after each cover crop in 2014 was analyzed in SAS using a mixed model.

RESULTS AND DISCUSSION

The results for cereal rye for 2014 showed significantly different biomass accumulation results for only the main effect of planting date at all three locations. Tables 2.5 and 2.6 detail the average weights of the biomass production for each planting date at each location. In 2015, planting date and fertilizer rate each showed significantly different impacts on biomass production in Kibler and Pine Tree. No significant difference was found for cereal rye at Rohwer in 2015. Rainfall and temperature were recorded for each location, and 2015 was a warmer and wetter year than 2014 (Tables 2.1, 2.2). The late season warmth at Rohwer, already the warmest location, may account for the lack of significant difference among planting dates, which allowed the rye to establish later in the season in 2015 than it had in 2014. Warmer soil may also have contributed to the fertilizer effects seen at Kibler and Pine Tree. Average biomass production at each location was higher in 2014 than in 2015. Planting dates for optimal biomass production are in September and early October, producing between 3,000 – 7,000 kg ha^{-1} depending on location. Since there was no significant difference found between 67 kg N ha^{-1} and 100 kg N ha^{-1}, recommendations for the lower rate would produce the desired results. Rohwer displayed the most impressive results for cereal rye in 2014, averaging 5,566 kg ha^{-1} even at the latest planting date of November 15. Contributing to the significance seen in 2015 may have been the reduced population due to failure to establish at multiple planting dates. Recommendation for cereal rye should rely more heavily on planting date than on fertilizer applications.

The results for wheat in 2014 showed significantly different biomass results for planting date only at all three locations, whereas neither fertilizer rate nor any interaction between planting date or fertilizer rate had an effect. The results for oats in 2015 followed the same trend, showing significantly different biomass production by planting date but no difference across fertilizer rates or across intersecting treatments. Both wheat and oats displayed the same optimal planting dates for biomass production as cereal rye, accumulating more growth when planted in September and early October, lasting through all of October for Rohwer. Fertilizer rate had no effect on either crop at any location apart from oats at Kibler, which showed that 34, 67, and 100 kg ha^{-1} of urea N all had the same effect of promoting growth. Given that the only other rate tested was 0 kg ha^{-1}, this result shows that the oats at Kibler responded the same to any amount of N application. Recommendations for wheat or oats should follow the recommendation of the other cereal, rye, and focus more on earlier planting dates than on fertilizer applications.

The results for tillage radish in 2014 showed significantly different biomass production across planting dates, and showed no difference between fertilizer rates at Kibler or Rohwer. Average biomass production is detailed in Tables 2.5 and 2.6. At Pine Tree, the difference between fertilizer rates was $p=0.0491$, and the rates showing the highest production were 0, 100, and 67 kg ha^{-1}. In 2015, radish at Kibler had insufficient data to analyze by planting date, failing to establish at all but one planting date. Nitrogen rate did not significantly affect the results of the biomass production at that date. At Pine Tree, radish did not show significant differences between planting dates, but at Rohwer, significant differences between planting dates were observed, again possibly influenced by the reduced sample population due to failure to establish at three of the five planting dates. Fertilizer rate did not significantly affect biomass production at any location in 2015.

The results for Austrian winter peas in 2014 showed significantly different results for biomass production by planting date at all three locations, and no difference across seeding rates at Pine Tree and Rohwer. Results at Kibler were $p=0.0372$ between seeding rates, with rates of 80 and 40 kg ha^{-1} showing the best biomass production over rates of 60 or 20 kg ha^{-1}. Average biomass production at all three locations for both years can be found in Tables 2.5 and 2.6. In 2015, planting date at Kibler did not have a significant effect, but planting date at Pine Tree and Rohwer did. Seeding rate did not significantly affect results at any location in 2015. Peas also failed to establish at several planting dates in 2015, and showed better biomass production when planted in early October than in September.

2015 was plagued by unusual growing conditions and insufficient data due to failure to establish by several crops. Overall, the winter cereals were more consistent in their response to planting date and fertilizer, while peas and radishes varied in their responses. This indicates that further study is needed in management practices for non-cereal cover crops to better refine the accuracy of the recommendations.

SOYBEAN YIELD AS INFLUENCED BY COVER CROP BIOMASS

A significantly higher soybean yield response was achieved after earlier planting dates for all except cereal rye at Pine Tree, which showed no significant difference. Soybean yield response after cereal rye ranged from 3,700-3,800 kg ha^{-1} at Pine Tree and 1,700-2,900 kg ha^{-1} at Rohwer. After wheat, the range of soybean yield response was 3,000-3,500 kg ha^{-1} at Pine Tree and 1,700-2,800 kg ha^{-1} at Rohwer. The range of soybean yield response after tillage radish was 2,700-5,200 kg ha^{-1} at Pine Tree and 1,500-2,600 kg ha^{-1} at Rohwer. After Austrian winter pea, the range of soybean yield response was 5,500-6,400 kg ha^{-1} at Pine Tree and 1,700 – 2,800 kg ha^{-1} at Rohwer. Soybean yield at Pine Tree ranged from a low of 3,026.8 kg ha^{-1} after the wheat planted on November 1st to a high of 6,374.4 kg ha^{-1} after the Austrian winter pea planted on September 15th. Soybean yield at Rohwer ranged from a low of 1,495.2 kg ha^{-1} after tillage radish planted on November 15th to a high of 2,923.2 kg ha^{-1} after cereal rye planted on September 15th. Cereal rye produced a significantly higher soybean yield response at Rohwer when planted early, before mid-October, but had no significant effect on soybean yield response at Pine Tree. Wheat produced a significantly higher soybean yield response at both locations when planted at September 15, the earliest date at Pine Tree or the three earliest dates at Rohwer. Tillage radish produced a significantly higher soybean yield response at Pine Tree when planted at September 15 and at Rohwer when planted at September 15 and October 1. Austrian winter pea showed a significant soybean yield increase at both locations when planted before November. Neither fertilizer rate nor seeding rate of the cover crop itself produced a significant effect on the soybean yield. Yield data can be found in Table 2.4.

CONCLUSIONS

Planting date was a better indicator of both cover crop biomass production and resultant soybean yield increases than was either fertilizer rate or seeding rate. Earlier planting dates were the most favorable to high biomass production, and the southernmost location at Rohwer had less difference between early planting dates than did either Kibler or Pine Tree. The implications for each crop vary by desired results. Results for rye showed that although the most significant effects directly related to soybean yield performance occur with earlier planting dates, later planting dates show good biomass production as well. Further research is needed to better correlate establishment with weather patterns and assist farmers in their management practices for specific conditions. Since neither fertilizer rate nor seeding rate showed a consistent positive impact, farmers should be advised to save their money and focus their efforts on attempting to get the cover crop in the ground as soon as possible after harvest. Radish had establishment issues in this study, and future studies should focus on the unique physiology of this tuberous brassica and how it responds to abiotic stresses.

Table 2.1. Monthly rainfall totals and average monthly temperatures for Kibler, AR, Colt, AR, and Rohwer, AR in 2014-2015.

Kibler

	August	September	October	November	December	January	February	March
Avg Temp ºC	27.6	23.6	18.7	8.1	6.4	4.3	3.1	11.4
Min Temp ºC	21.8	18.1	12.1	1.6	2.9	-1.8	-2.8	5.5
Max Temp ºC	33.8	29.1	25.2	14.8	9.8	10.9	9.3	17.3
Precip. cm	4	17.6	20.1	4	5.9	5.6	6.1	11.5

Pine Tree

	August	September	October	November	December	January	February	March
Avg Temp ºC	26.8	23.6	18.7	7.7	7.3	3.7	1.3	9.3
Min Temp ºC	21.1	16.8	12.1	2.1	3.5	-1.5	-3.7	4.5
Max Temp ºC	32.5	30.4	25.3	13.3	11	9	6.4	8.6
Precip. cm	1	0.6	10.6	6.9	6.8	5.6	6.1	15.3

Rohwer

	August	September	October	November	December	January	February	March
Avg Temp ºC	26	24	18.9	8.9	8	3.7	3.2	11.3
Min Temp ºC	21.1	18.5	12.8	3	2.9	-2	-1.9	7.1
Max Temp ºC	30.9	29.5	25	14.7	13.1	9.4	8.3	13.3
Precip. cm	15.6	4.1	19.6	7	8.1	9.1	7.6	21.1

Table 2.2 Monthly rainfall totals and average monthly temperatures for Kibler, AR, Colt, AR, and Rohwer, AR in 2015-2016.

Kibler

	August	September	October	November	December	January	February	March
Avg Temp ºC	26.8	24.8	18.6	12.7	9.6	4.7	9	13.4
Min Temp ºC	21.1	18.7	11.7	6.9	3	-1.3	1.9	6.7
Max Temp ºC	32.4	30.9	25.5	18.6	16.2	10.7	16.1	20.1
Precip. cm	11.3	6.5	3.9	24	27.5	1	4.5	11.8

Pine Tree

	August	September	October	November	December	January	February	March
Avg Temp ºC	25.4	24.2	17.7	13.2	11.3	4	7.9	14.9
Min Temp ºC	19.3	17.8	11.1	8.3	6.2	-0.6	2.3	9.4
Max Temp ºC	31.5	30.6	24.4	18.1	16.5	8.6	13.4	20.4
Precip cm	10.7	5.6	6.4	27.8	18.4	7.4	4.3	0.5

Rohwer

	August	September	October	November	December	January	February	March
Avg Temp ºC	26.6	24.6	18.6	14	11.5	5.1	9.1	14
Min Temp ºC	21.2	18.5	12.4	9.6	6.7	0.7	4.1	9.3
Max Temp ºC	31.8	30.7	24.9	18.4	16.2	9.4	14.2	18.7
Precip. cm	4.1	2.7	11.4	24.6	2.2	7.6	6.2	9.7

Table 2.3 Analysis of variance for the effects of planting date, fertilizer/seeding rate, and the interactions for each at Kibler, AR, Colt, AR, and Rohwer, AR, (alpha ≥ 0.05).

Effect	df	Cereal Rye	Wheat	Oats	Peas	Radish
			Kibler			
2014 Date	3	<0.0001	<0.0001	N/A	<0.0001	<0.0001
2014 Rate	3	0.1376	0.1300	N/A	0.0372	0.7769
2014 Date x Rate	9	0.5962	0.1622	N/A	0.0807	0.3253
2015 Date	2	<0.0001	N/A	<0.0001	0.2291	FTE*
2015 Rate	3	0.0003	N/A	0.0087	0.7587	0.6184*
2015 Date x Rate	6	0.1895	N/A	0.2628	0.8355	FTE*
			Pine Tree			
2014 Date	4	<0.0001	<0.0001	N/A	<0.0001	<0.0001*
2014 Rate	3	0.2969	0.1683	N/A	0.9725	0.0491*
2014 Date x Rate	12	0.6284	0.7073	N/A	0.1374	0.2696*
2015 Date	2	<0.0001	N/A	<0.0001	<0.0001*	0.3691
2015 Rate	3	0.0219	N/A	0.1785	0.8855*	0.9597
2015 Date x Rate	6	0.4530	N/A	0.9866	0.9783*	0.9276
			Rohwer			
2014 Date	4	<0.0001	<0.0001	N/A	<0.0001	<0.0001
2014 Rate	3	0.5091	0.8949	N/A	0.7994	0.5886
2014 Date x Rate	12	0.9922	0.0895	N/A	0.4396	0.1902
2015 Date	1	0.0854	N/A	0.0081	0.4409	0.0004
2015 Rate	3	0.3143	N/A	0.4478	0.4505	0.2294
2015 Date x Rate	3	0.7807	N/A	0.6565	0.2256	0.2286

*denotes fewer df due to failure to establish

Table 2.4. Soybean yield following cover crops at the Pinetree Research Station (PTRS) and Rohwer Research station (RRS) in 2015 (alpha ≥0.05).

Cover Crop	Planting Date	Pinetree	Rohwer
		-------------soybean yield (kg ha^{-1})-------------	
Cereal Rye	Sept. 15	3830 a	2923 a
Cereal Rye	Oct. 1	3734 a	2709 a
Cereal Rye	Oct. 15	3826 a	2045 b
Cereal Rye	Nov. 1	3759 a	1823 bc
Cereal Rye	Nov. 15	3801 a	1697 bc
Wheat	Sept. 15	3486 a	2583 ab
Wheat	Oct. 1	3200 bc	2810 a
Wheat	Oct. 15	3070 bc	2436 b
Wheat	Nov. 1	3037 c	1831 c
Wheat	Nov. 15	3272 b	1714 c
Radish	Sept. 15	5170 a	2600 a
Radish	Oct. 1	5107 a	2243 b
Radish	Oct. 15	4582 b	1667 c
Radish	Nov. 1	4024 c	1613 c
Radish	Nov. 15	3324 d	1495 c
Pea	Sept. 15	6374 a	2835 a
Pea	Oct. 1	6182 ab	2675 a
Pea	Oct. 15	5635 ab	2348 b
Pea	Nov. 1	5605 b	1747 c
Pea	Nov. 15	5524 b	1676 c

Levels not connected by same letter within a cover crop species are significantly different.

Table 2.5 Average total above-ground biomass (kg ha^{-1}) for each cover crop by planting date and location for 2014-2015 (alpha ≥ 0.05).

Kibler

	Cereal Rye		Tillage Radish		Austrian Winter Pea		Wheat	
Sept. 15	6698	**A**	4535	**A**	5172	**A**	5243	**A**
Oct. 1	6924	**A**	4340	**B**	5174	**A**	4885	**B**
Oct. 15	4284	**B**	3021	**C**	4128	**B**	4276	**C**
Nov. 1	3916	**C**	2357	**D**	2891	**C**	2813	**D**
Nov. 15	FTE		FTE		FTE		FTE	

Pine Tree

	Cereal Rye		Tillage Radish		Austrian Winter Pea		Wheat	
Sept. 15	5914	**A**	5243	**A**	5319	**A**	5462	**A**
Oct. 1	6083	**A**	5166	**A**	5351	**A**	5353	**A**
Oct. 15	4887	**B**	4225	**B**	4740	**B**	4584	**B**
Nov. 1	3404	**C**	FTE		4596	**B**	3095	**C**
Nov. 15	3344	**C**	FTE		4275	**C**	2194	**C**

Rohwer

	Cereal Rye		Tillage Radish		Austrian Winter Pea		Wheat	
Sept. 15	6235	**A**	5500	**A**	5728	**A**	5708	**A**
Oct. 1	6289	**A**	5579	**A**	5677	**A**	5618	**A**
Oct. 15	6088	**A**	5660	**A**	5572	**A**	5676	**A**
Nov. 1	5599	**B**	4646	**B**	5184	**B**	5078	**B**
Nov. 15	5566	**B**	4542	**B**	4304	**C**	5132	**B**

*FTE denotes failure to establish

Levels not connected by same letter are significantly different.

Table 2.6 Average total above-ground biomass (kg ha^{-1}) for each cover crop by planting date and location for 2015-2016 (alpha ≥0.05).

	Cereal Rye		Tillage Radish		Austrian Winter Pea		Oats	
Kibler								
	Cereal Rye		Tillage Radish		Austrian Winter Pea		Oats	
Sept. 15	7507	**A**	FTE		3152	**A**	8461	**A**
Oct. 1	4806	**B**	FTE		2256	**A**	8045	**A**
Oct. 15	1888	**C**	3339	**A**	2874	**A**	3501	**B**
Nov. 1	FTE		FTE		FTE		FTE	
Nov. 15	FTE		FTE		FTE		FTE	
Pine Tree								
	Cereal Rye		Tillage Radish		Austrian Winter Pea		Oats	
Sept. 15	3371	**A**	2555	**A**	2219	**B**	4781	**A**
Oct. 1	3520	**A**	3139	**A**	4273	**A**	4302	**A**
Oct. 15	1550	**B**	2958	**A**	FTE		2194	**B**
Nov. 1	FTE		FTE		FTE		FTE	
Nov. 15	FTE		FTE		FTE		FTE	
Rohwer								
	Cereal Rye		Tillage Radish		Austrian Winter Pea		Oats	
Sept. 15	2982	**A**	8522	**A**	2759	**A**	5956	**A**
Oct. 1	FTE		FTE		FTE		FTE	
Oct. 15	FTE		FTE		FTE		FTE	
Nov. 1	FTE		FTE		FTE		FTE	
Nov. 15	2393	**A**	4648	**B**	2313	**A**	4215	**B**

*FTE denotes failure to establish

Levels not connected by same letter are significantly different.

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CHAPTER 3

Nitrogen Accumulation in Leguminous Cover Crops

ABSTRACT

Arkansas farmers often turn to legume cover crops to reduce nitrogen (N) fertilizer needs in the following cereal cash crops. A leguminous cover crop fixes atmospheric N and can provide a farmer with “N credits,” which is best understood as existing soil N after utilizing a leguminous cover crop. Those N credits can then be subtracted from the following cereal cash crop’s season-total N needs. This research analyzes how species and planting date can affect total N accumulation, looking at three species in two locations. Austrian winter pea (*Pisum sativum*) at a seeding rate of 40.4 kg ha^{-1} from the previous planting date study was analyzed for N accumulation, while peas, hairy vetch (*Vicia villosa*), and crimson clover (*Trifolium incarnatum*) were planted at an additional location and compared. The aboveground biomass was oven-dried, ground, and analyzed for N. Austrian winter pea did not show significant differences in N uptake when using one seeding rate at five different planting dates, but outperformed both vetch and clover in total tissue N concentration as well as total N accumulation when analyzed at one location.

INTRODUCTION

Plants which fall under the category of “legumes” are capable, via symbiotic bacterial colonies on their roots, to fix atmospheric N in their root systems and release it into the soil upon decomposition. Leguminous winter cover crops are an excellent way to reduce dependency on chemical N fertilizer because of this fixation process, which results in net “N credits” in the soil (O’Leary, 2013). This enriched soil means that less chemical N will be required for the subsequent crop, an outcome that has beneficial impacts on both the environmental and economic concerns of Arkansas farmers (Decker, 1994).

Austrian winter pea is an excellent choice for N accumulation and has a higher water use efficiency (WUE) than other legumes (Cousin, 1997; Mahler, 1989). It has a much lower C:N ratio than small cereal grains, meaning that it decomposes more rapidly in the late winter and early spring than those crops. Peas make an excellent forage for cattle and other animals, and they have a vining, trailing growth habit that stays lower to the ground and can help mitigate weeds efficiently, despite producing less biomass than something like rye, a cover traditionally used for weed suppression (Cousin, 1997). It is a popular leguminous cover crop choice and therefore quantifying the relative N fixation compared to other legumes is of interest to Arkansas farmers.

Hairy vetch is an introduced species which thrives throughout North America (Frame, 2016). It is a hardy cover that produces large quantities of biomass in cooler temperatures than other legumes, and it hosts a variety of beneficial insects including bumble bees (*Bombus spp.*). Seeds are susceptible to insect damage by the vetch bruchid (*Bruchus brachialis*), but this cover crop does not otherwise have a significant problem with many pest insects. Vetch also a trailing growth habit and a shallow root system, so it is often planted with rye. Its high percentage of crude protein makes it another good choice for winter forage (USDA, 2016).

Crimson clover is a leguminous winter cover crop that can be grown on poorer soil textures than other legumes, given enough phosphorus and a pH of 6.0-7.0. It is less desirable to use as a winter forage, however, because of the increased risk of bloat (USDA, 2016). Clover is easy to seed and generally establishes well, but these traits may prove detrimental if the clover begins to take over nearby areas previously covered with native vegetation. Many of the same insects that feed on other legumes will also feed on clover, including both beneficial and pest insects. Clover roots are shallow and do not significantly impact the bulk density of the soil. Some studies indicate that clover actually immobilizes less N than rye (Ranells, 1997).

Soybeans following a legume cover crop face a unique set of interactive possibilities. Given that soybean is also a legume, the possible risk of insect and/or disease transference is increased. Some farmers run the risk of increasing their cutworm (*Agrotis spp.*), corn earworm (*Helicoverpa zea*), tobacco budworm (*Heliothis zea*) and tarnished plant bug (*Lygus lineolaris*) populations, which are all leguminous pests, as well as a variety of cotton pests and/or diseases like *Sclerotinia minor*, a fungal disease (Dabney et al., 2007; Koike, 1996).

Another consideration is that N-enriched soil following a leguminous winter cover crop could potentially decrease the amount of N fixed by the soybean. This rotational choice could be beneficial in situations where the soil is very sandy or otherwise less capable of mitigating N losses, or where the farmer wishes to use starter fertilizer but cannot afford it. Lastly, farmers may consider whether the other benefits of a leguminous cover, such as good forage, make a case by themselves for using that cover.

MATERIALS AND METHODS

This research was carried out in two locations with three cover crop species. Four plots for Austrian winter pea were established at the Vegetable Sub-Station (VSS) near Kibler, AR. They were seeded at a rate of 40.4 kg ha^{-1}, using a range of five planting dates. Plots for hairy vetch and crimson clover were established at the Arkansas Agricultural Research and Extension Center (AAREC) in Fayetteville, AR, at 22 kg $ha^{-1}$and 15 kg ha^{-1}, respectively, in the experiment planted on September 16, and 22 kg ha^{-1} and 17 kg ha^{-1} in the experiment planted September 24. The VSS plots were part of the planting date experiment described in Chapter 2, and the AAREC plots were part of an herbicide study designed to evaluate the effects of both herbicide brand and residual herbicide effect from summer application on winter cover crop establishment. The results of that study (unpublished data) indicated that neither herbicide brand nor application timing/ herbicide residuals influenced winter cover crop establishment or growth, rendering those cover crops suitable for use in this study. The herbicide brands, application rates, and application timing can be found in Table 3.1 and Table 3.2.

The Austrian winter pea plots at Kibler were unirrigated, while the pea, vetch, and clover plots at the AAREC were irrigated with 1.3 cm of overhead irrigation to activate the herbicides. Table 3.3 details the temperature, rainfall and irrigation that a species received. The pea plots at the VSS consisted of a Roxana silt loam soil, and the vetch and clover plots at the AAREC were established on a Captina silt loam soil. One set of samples for Austrian winter pea were taken from the previously described planting date study in Chapter 2, and as such were part of a 5 x 4 factorial design with planting date and seeding rate. However, since only one seeding rate of 40.4 kg ha^{-1} was analyzed in this study, the design becomes a one-factor completely randomized design. In the analysis among crops, the data from the two planting dates is analyzed separately. The original split-plot factor, herbicide, was found insignificant, and so the single factor becomes plant species. Thus, the design for peas, hairy vetch, and crimson clover is also a one-factor completely randomized design.

TISSUE SAMPLING AND ANALYSIS

A 0.9 x 0.9 m section of the aboveground biomass of each species was sampled in late March and oven-dried at 50^{oC} for two weeks and weighed to determine total above-ground biomass production. The dried plant tissue was subsequently ground in a Wiley Mill model 4 (Thomas Scientific) to pass through a 1-mm sieve, subsampled (0.1 g), and analyzed for total N by combustion utilizing an Elementar vario Macro (Elementar Analysensysteme GmbH, Hanau, Germany).

STATISTICAL ANALYSIS

Completely randomized designs were used to separately assess N accumulation by species and N accumulation by planting date. The first design had cover crop species as its only factor, since herbicide program (the original split-plot factor) has been determined (unpublished data) to have had no effect on cover crop growth. The second design had planting date as its only factor since the original split-plot factor of seeding rate was disregarded due to the results of experiment one as described in Chapter Two, and only the 40.4 kg ha^{-1} seeding rate was analyzed. Analyses were conducted in JMP Pro 12 and alpha was set at ≤0.05.

RESULTS AND DISCUSSION

NITROGEN ACCUMULATION BY SPECIES

Average kg N ha^{-1} for all AAREC analyses can be found in Table 3.4. The Elementar vario Macro uses jet injection of oxygen to fully combust the samples for 100% recovery. Nitrogen accumulation was found to be highest in Austrian winter pea. It did not significantly differ in Austrian winter peas planted in Kibler or Pine Tree across five different planting dates, assuming establishment. Although a significant difference was found between planting dates at Rohwer, the data was compromised by failure to establish, leaving only the September 15 and November 15 planting dates available for analysis. It seems inevitable that planting two months apart would show significantly different results. When comparing Austrian winter pea to hairy vetch and crimson clover, using two early planting dates at the AAREC, peas and vetch had significantly higher N concentrations at each date. Nitrogen accumulation was the highest in

Austrian winter pea, averaging 100 kg ha^{-1} when planted in September. At the later planting date of September 24, hairy vetch was not significantly different than pea, while crimson clover was significantly lower in tissue N concentration than either pea or vetch. At the earliest planting date of September 16, pea again had the highest N accumulation and was significantly higher than vetch, while vetch was still also significantly higher than clover. These results indicate that peas may be the best choice when faced with later planting dates due to their more robust growth and N accumulation later in the season. The results also show that hairy vetch is an excellent substitute when earlier planting dates are available.

Nitrogen Credits

Calculating the amount of N credits one can safely assume from a cover crop is more complex than simply measuring the amount of N in the cover crop tissue and extrapolating from there. Tissue sampling, while a good indicator and the method used in this study, does not account for N accumulation in roots. Therefore, adjustments must be made when calculating N credits from purely aerial biomass tissue (O'Leary, 2013). The amount of available N in the soil will be different depending on soil texture, soil moisture, and soil temperature. The raw tissue N concentration can be found in Tables 3.4 and 3.5, and calculations may be estimated using the guidelines from the University of Minnesota Extension Office.

Recommendations

The results of this study show us the relative N that will be available to farmers after planting these different species of cover crops. Farmers should make their choices based on the price of seed, inoculant, and N fertilizer that year. In general, Austrian winter pea and hairy vetch will provide more N than will crimson clover, in part due to greater biomass production and in part due to fixation capability. If the harvest date of the preceding cash crop precludes an early planting date for the cover crop, Austrian winter pea biomass is less affected than is either hairy vetch or crimson clover, and thus peas will continue to produce sufficient biomass when planted into mid-October, and sometimes even later in warmer parts of the state.

CONCLUSIONS

Austrian winter pea is the likeliest winter legume to provide ample biomass and N credits across the state and with varying planting dates, ranging into November in some cases. A low seeding rate of 40.4 kg ha^{-1} (40 lbs/acre) is sufficient to gain the benefits of this crop, which is good for farmers considering the higher cost of legume seed. This pea is also a good winter forage, making it a hardworking, adaptable multitasker when it comes to choosing the right legume, although consumption of the aerial biomass as forage will reduce the available N to the next crop. Averaging across planting dates, Austrian winter pea provides 85 kg N ha^{-1} from its aerial tissue, which is less than the average of biomass from earlier planting dates but still impressive, and because it has a C:N ratio of around 13:1 it decomposes relatively quickly, meaning that more of that tissue N is available for the next summer crop's use. Estimating the total N in the aerial parts and roots from the more desirable early planting dates gives a total N of 350 kg ha^{-1}, and the extension office of the University of Minnesota has shown that at least 50% of that is plant-available to the next crop (O'Leary, 2013). The warmer soil temperatures in Arkansas may contribute to an even higher rate of availability, meaning that Austrian winter pea planted at an early date can reduce fertilizer needs by 175 kg ha^{-1} or more.

Hairy vetch provides a good secondary option to Austrian winter pea, especially if it can be planted earlier in the season. Vetch provides approximately 340 kg N ha^{-1}, which equates to roughly 172 kg ha^{-1} of available N for the next crop. Like peas, vetch is a good winter forage and produces sufficient biomass for both forage and erosion-reducing ground cover. Crimson clover, in contrast, should be used sparingly as a forage because it can be detrimental to cattle when consumed in large quantities. It has the lowest amount of available total N at approximately 113 kg ha^{-1}, and the lowest biomass, meaning that it will not be as broadly beneficial in terms of controlling erosion, improving water infiltration and retention, and suppressing weeds. If the previous or subsequent cash crop is soybeans, any legume cover crop must be monitored to prevent furthering a legume-specific pest or disease.

Farmers should be made aware of the various interactions at work in legume cover crops and how that relates to their ultimate benefit. Recommendations may vary year-to-year based on available planting date, desired benefit, monoculture cover crop vs. mixed, seed cost, inoculant cost, N fertilizer cost, federal incentives program availability, and following cash crop species. Overall, Austrian winter pea should be more highly recommended based on the available current research, although more research is needed to verify the results and tease apart the various factors impacting those results.

Table 3.1 Herbicide rate by brand

HERBICIDE	COMMON NAME	RATE (G AI/HA)
HARNESS	Acetochlor	140.2
ZIDUA	Pyroxasulfone	9.3
DUAL MAGNUM	*S*-metolachor	87
BALANCE PRO	Isoxaflutole	5.7
CALLISTO	Mesotrione	6.6
LAUDIS	Tembotrione	5.7
AATREX	Atrazine	140.2
SENCOR DF	Metribuzin	35
COTORAN 4	Fluometuron	70
DIREX	Diuron	70
BRAKE	Fluridone	17.5
STAPLE	Pyrithiobac	4.6
ENVOKE	Trifloxysulfuron	0.49
NEWPATH	Imazethapyr	4.37
FLEXSTAR	Fomesafen	24.6
VALOR	Flumioxazin	4.5
SPARTAN	Sulfentrazone	17.5

Table 3.2. Application timing of herbicides.

HERBICIDE	COMMON NAME	RATE (G AI/A)	APPLICATION TIMING
AATREX	Atrazine	2243	12” Corn
ZIDUA	Pyroxasulfone	476	V4 Corn
CAPRENO	Thiencarbazone + Tembotrione	33.6 + 151	V5 Corn
CALLISTO	Mesotrione	210	V8 Corn
LAUDIS	Tembotrione	183	V9 Corn
WARRANT	Acetochlor	2313	30” Corn
OUTLOOK	Dimethenamid	2208	36” Corn
DUAL II MAGNUM	*S*-metolachlor	4283	40” Corn

Table 3.3. Irrigation, rainfall and temperature at the Arkansas Agricultural Research and Extension Center (AAREC).

	AVERAGE MONTHLY TEMP ºC		**MAX TEMP ºC**		**MIN TEMP ºC**		**PRECIPITATION CM**		**IRRIGATION CM**	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
AUG	25.6	23.4	31.3	29.2	19.9	17.5	6.6	6.8	3.3	3.3
SEPT	21.3	23.1	27.1	28.4	15.6	17.7	11.4	4.7	3.3	3.3
OCT	16.6	16.1	22.8	22.3	10.5	9.9	16.6	5.8	3.3	3.3
NOV	3.1	11.6	7.7	17.2	-1.6	5.9	1	10.6	3.3	3.3
DEC	4.5	7.6	8.3	13.8	0.8	1.4	7.6	32.3	3.3	3.3
JAN	1.9	0.7	7.8	5.4	-3.9	-4	1.4	0.7	3.3	3.3
FEB	-0.4	6.5	5.4	12.9	-6.3	0.1	0.1	1.5	3.3	3.3
MAR	9	11.5	14.4	17.6	3.5	5.4	8.2	9.7	3.3	3.3

Table 3.4 Above-ground N accumulated (kg ha^{-1}) per cover crop in the AAREC studies (alpha ≥ 0.05).

	Austrian winter pea	Hairy vetch	Crimson clover
Study 1	111.0 **A**	109.7 **A**	70.2 **A**
Study 2	116.4 **A**	103.8 **B**	73.1 **A**

Levels not connected by same letter are significantly different.

Table 3.5 Above-ground N accumulated (kg ha^{-1}) per planting date at Kibler, Pine Tree, and Rohwer (alpha ≥0.05).

	Kibler	Pine Tree	Rohwer
Sept. 15	72.4 **A**	60.0 **B**	110.8 **A**
Oct. 1	47.7 **B**	140.6 **A**	FTE
Oct. 15	70.0 **A**	FTE	FTE
Nov. 1	FTE	FTE	FTE
Nov. 15	FTE	FTE	90.3 **B**

*FTE denotes failure to establish

Levels not connected by same letter are significantly different.

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CHAPTER 4

Conclusions

CONCLUSIONS

The purpose of this research was to respond to the recent interest in sustainable agriculture through winter cover cropping systems. Although cover crops research has been done in the Midwest, Arkansas farmers need recommendations suited to our climate, soil textures, and management practices (Dabney et al, 2007; Fageria et al, 2005; Langdale et al, 1991; Reeves, 1994). This foundational research is critical in establishing best management practices for a wide variety of cover crop species across the state, per the needs of the farmer. Comparing earlier versus later planting dates for cover crops is of interest because of the constraints of harvesting the previous summer's cash crop.

Related to best management practices is the question of whether to apply fertilizer, when planting a non-leguminous crop, or at what rate to seed the leguminous crop (Cassman et al, 2002; Tonitto et al, 2006). Since cover cropping is, in many instances, a way to control input costs as well as measure to reduce damaging environmental impacts, farmers need to know the minimum amounts of fertilizer or legume seed, respectively, that they can purchase to achieve their optimum biomass production from their cover crops (Villamil et al, 2006; Wyland et al, 1996). The first experiment in this research looked at five cover crops in three locations, drill seeded in 19 cm rows in a split plot design with planting date as the main factor and fertilizer rate/seeding rate as the split plot factor. There were four replications of each split plot factor in each 1.8 x 6.1 m whole plot. Locations were analyzed separately to give an idea of how the crops fared across the state, and rainfall and temperature were recorded for reference. Biomass samples were collected in the spring from a 0.9 x 0.9 m section of bordered row, placed in paper bags, oven-dried at 50ºC for 2 weeks, and then weighed in the bags. An average bag weight was subtracted from the recorded biomass weights. Yield data from the following year's soybean crop was also recorded and analyzed.

The results for both years showed that planting date was the most crucial optimization factor, in every location and with every crop. Fertilizer or seeding rate was occasionally significant, and the data from the 2014 planting dates was more robust than the data from the 2015 planting dates due to some establishment failure in 2015. The interaction of rate and planting date never played a significant role in determining biomass production. Earlier planting dates produce the most biomass, and less hardy crops like peas and radish tend to fail to establish when planted too late. In the right conditions, hardier winter cereals can produce sufficient biomass (>3,000 kg ha^{-1}) for their primary roles in weed suppression and erosion control (SARE, 2007).

Further, the use of leguminous cover crops begs the question of how much N is available after sowing those crops (Cassman et al, 2002). The second experiment in this research compares different legumes to provide more accurate information on which legume seed to choose. There were three legumes in one location analyzed for tissue N, which in crops with a lower C:N ratio is readily available to the next cash crop due to the rapid decomposition of the tissue. The legumes used were Austrian winter pea, hairy vetch, and crimson clover. Cover crops were planted in strips in their respective plots at the AAREC in Fayetteville, AR on two different dates at a single seeding rate for each crop. The design for the original herbicide study was a split-plot design, but since herbicide was disregarded for the purposes of this study, ensuing design was completely randomized. Plots were irrigated once via overhead irrigation to activate herbicides, and rainfall and temperature were also recorded. 0.9 x 0.9 m sections of biomass were sampled from each plot and oven dried at 50ºC for two weeks, after which they were analyzed for tissue

N content. Overall, Austrian winter pea was found to have the highest tissue N content of the three species when planted at an early date. Hairy vetch had the second highest N content and crimson clover had the lowest, and planting dates for those species were not analyzed. The experimental design for the Austrian winter pea which was evaluated for planting date effects was also a completely randomized design, given that it was originally a split-plot design with seeding rate as the split-plot factor, and that only one seeding rate was analyzed due to the results of experiment one.

These experiments show us that early planting dates are vitally important, and that for increasing soybean yield, early planting dates are the only ones which are significant. Further research is needed to ascertain the potential benefits from cover crops which do not meet the biomass requirements to positively impact yield, such as a late-planted rye which is neutral regarding yield but which prevents erosion or weed emergence on a scale which may take multiple years to become statistically visible (Reeves, 1991; SARE, 2007,). Nitrogen fertilizer recommendations for cover crop performance and maximum net financial benefit should lean toward zero kg ha^{-1}, since the evidence for significant benefit of fertilizer was inconsistent. Advisors should also work with farmers to plan a multi-year crop rotation to take harvest date and long-term benefits into consideration for how to choose a cover crop. If N credits are the primary concern, Austrian winter pea should be favored above hairy vetch or crimson clover.

The results of these studies indicate that, although further research for specifically Arkansan growing conditions is needed, it is safe to push an early planting date as the most important factor in cover crop success. Further, legume species with higher biomass such as Austrian winter pea provide more total N to use toward the next cash crop. Benefits of cover cropping in Arkansas can be reaped with a minimum of added costs and should be encouraged statewide for farmers interested in a more sustainable approach to agriculture.

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