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Short-term Effects of Winter Cover Crops on Soil Properties, Yield, and Partial Returns in a No-tillage Soybean Rotation

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Short-term Effects of Winter Cover Crops on Soil Properties, Yield, and Partial Returns in a No-tillage Soybean Rotation

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Abstract

Cover crops have the potential to provide many benefits including weed suppression, erosion control, and improvements to soil quality. These benefits can be affected by species, biomass accumulation, and management practices. Although large amounts of biomass are good for maximizing benefits, it can result in problems for establishing the subsequent crop. Soybean [*Glycine max* (L.) Merr.] accounts for over 50% of Arkansas crop hectares annually; therefore, understanding the effect that a cover crop can have on the following soybean crop is crucial to the successful implementation of cover crops within the state. A study was established to evaluate winter cover crops as an alternative to traditional Arkansas practices, such as winter fallow, as well as winter wheat (*Triticum aestivum* L.) soybean double-crop system, and the effect each cropping system has on soybean yield and partial returns. Additionally, a goal of this study was to assess a variety of cover crop species and blends as well as their effect on aboveground biomass accumulation, nutrient uptake, and stand establishment of the following soybean crop. Soil organic matter (SOM) and pH were also used to evaluate overall soil health following three full rotations of each winter treatment. Results of the study show that winter cover crops do not affect the following soybean crop establishment, but had a positive influence on soybean yield and partial returns in a no-tillage system. Except for blue lupin (*Lupinus angustifolius*), each cover crop treatment proved to be an equally viable alternative to a traditional double-crop system and more profitable than a winter fallow system. Cover crops not only have an immediate impact of increasing soybean yield, but cover crops also have the potential to provide long-term benefits. Previous research has shown that increased biomass production typically increases SOM and results of this study indicate that cover crop treatments produced up to four times as much aboveground biomass compared to a winter fallow management strategy. Treatments that produced the most biomass also accumulated the most aboveground nutrient contents for the macronutrients nitrogen (N), phosphorus (P), and potassium (K). There were no differences in soil health calculations, but each treatment received a “good” soil health score. Our results indicate that winter cover crops provide a promising alternative to the winter wheat soybean double-crop system and winter fallow management program and with continuous management, soil quality can be improved.

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Chapter One: Introduction

Interest in cover crops has been prompted by increased concern regarding agronomic and environmental factors, such as soil erosion, soil health, weed suppression, and soil nutrient retention. All of these factors have the potential to hinder the yield of economically important crops, like soybean [*Glycine max*. (L.) Merr.], and contribute to the degradation of surrounding non-agricultural ecosystems. Literature indicates that cover crops have the potential to alleviate these concerns while maintaining or increasing soybean yields. With increased producer support through cost-sharing programs administered by the Natural Resource Conservation Service (NRCS), there is a greater demand for unbiased, land grant university (LGU) research to guide producers and crop consultants on the best way to implement cover crops into Arkansas crop production systems.

Arkansas Soybean Production

Soybean was introduced to Arkansas in 1925 by Jacob Hartz Sr. (Arkansas Soybean Promotion Board, 2016). Since its introduction, the soybean has grown in popularity among producers and is the primary row crop produced in Arkansas with more hectares planted each season than rice (*Oryza sativa* L.), corn (*Zea mays* L.), or cotton (*Gossypium hirsutum* L.).

In Arkansas, three crops dominate the majority of hectares dedicated to row crop production: corn, rice, and soybean (USDA-National Agricultural Statistics Service, 2017). Corn and rice are typically planted early in the spring, while soybean is planted in late spring. Mid-April to July soybean has such a wide planting window that they are appealing to Arkansas producers who also grow corn and rice, which both have early March to mid-May planting windows. Versatility allows producers to spread out their labor, costs, and risk.

Soybean is a legume of the Fabaceae family (The Editors of Encyclopaedia Britannica, 2018a), which are unique plants in that they can fix their nitrogen (N) through biological N fixation (BNF). The BNF process starts with a nodule forming on legume roots, and *Rhizobium* bacteria in the soil invade the nodule. The plant provides habitat and nutrients for the bacteria to survive, and the bacteria fix atmospheric N for the plant to utilize throughout the growing season (Flynn and Idowu, 2015).

The market for soybean-based products is extensive. On top of soybean meal being an excellent supplement for livestock, due to its large protein content, human consumption of soybean foods is becoming more popular. Popular soy foods are tofu, soymilk, and edamame. Edamame, which is simply a fresh vegetable soybean, is a growing trend for soybean use in the United States. Mulberry, Arkansas is the edamame capital of the United States (Kaiser and Ernst, 2016).

It has been shown that soybean contains isoflavones and proteins that have numerous health benefits, such as lowering the risk for coronary heart disease (Messina, 2018). Oil from soybean is also popular for baking and frying many popular foods. Roughly one-quarter of all the soybean oil produced in the United States is used to produce biodiesel. Biodiesel produced from soybean oil has been shown to reduce greenhouse gas emissions as well as increase energy-use efficiency. Soybean-oil biodiesel also provides a price supplement to soybean of 15 % (Krull, 2018).

According to the USDA's 2012 Census of Agriculture, soybean was grown on 301,343 farms in the United States. That total was a 6 % increase from the previous Census of Agriculture in 2007. Since 1924, hectares planted in soybean have been on a steady climb. In

1924, there were 0.6 million hectares planted in the U.S and, in 2017, there were 5 million hectares planted (USDA- National Agricultural Statistics Service, 2012).

In 2017, 1.4 million hectares of soybean were planted in Arkansas alone (USDA- National Agricultural Statistics Service, 2018a). Of total planted area, 1.4 million hectares were harvested, with an average per hectare yield of 3,430 kg ha^{-1}, which is a record high for Arkansas (USDA-National Agricultural Statistics Service, 2018b). The 2017 projected production value of soybean in Arkansas was 1.74 billion dollars. The total planted hectares for the state of Arkansas in 2018 was up to 1.45 million hectares, and forecast experts estimate the total harvested soybean hectares to be around 1.44 million hectares (USDA- National Agricultural Statistics Service, 2018a). Soybean ranks as the number one commodity in Arkansas in terms of hectares grown, while soybean production value ranks as second in the state behind only broilers and 11th in the nation (University of Arkansas Extension Division of Agriculture, 2017).

To maximize yield, irrigation is often recommended to supplement rainfall. Yields cannot be maximized if there is inadequate moisture available to the plant during the growing season, especially during reproductive growth. In addition to yield maximization, some farm loan offices are taking into account a grower's ability to irrigate a majority of their crop before approving a loan (Tacker and Vories, 2000). Furrow irrigation is the predominant form of irrigation used in Arkansas soybean production systems. Most fields are planted on raised beds, and polypipe is utilized for irrigation in the furrows. The next most popular form of soybean irrigation is flooding. Out of the 1.4 million hectares of soybean harvested in 2017, 84.5% were irrigated. Soybean that were irrigated averaged 3,558 kg ha^{-1} while non-irrigated soybean only averaged 2,751 kg ha^{-1} (USDA-National Agricultural Statistics Service, 2017). The total cost per hectare, following the initial cost of irrigation equipment, is approximately $106.31, which includes the cost of energy, maintenance, polypipe, and other supplies. Profits typically increase by $254.90 per hectare, investing in irrigation well worth the cost (University of Arkansas, 2018).

Arkansas Wheat

Wheat (*Triticum aestivum*) is a member of the Poaceae family (USDA- Natural Resources Conservation Service, 2019a) and is grown across the globe in many different countries and climates. While wheat growth is optimized within specific latitudes, wheat can be successfully cultivated anywhere between the Arctic Circle and higher altitudes near the equator (Briggle and Curtis, 1987).

Since its introduction into the United States in the late 1700s, wheat has seen a rise and fall in popularity. The largest recorded number of winter wheat hectares planted in the United States was in 1981, with 26.5 million. In 2017, only 13.2 million hectares of winter wheat were planted, which was roughly a 50% reduction in the planted area since the height of winter wheat popularity (USDA- National Agricultural Statistics Service, 2018a). The United States produced around 47 million metric tons of wheat in the 2017/2018 growing season, which was 6.25% of the world's total wheat production for that growing season (USDA- National Agricultural Statistics Service, 2018c).

United States wheat producers could be struggling to compete with growers from overseas. Wheat producers in Russia and the European Union are gaining prominence, causing a decline in the United States' share of the global wheat market. Along with the global competition, low net returns from the crop and changes to government programs have also led to the decline of the United States' production (USDA Economic Research Service, 2019). The weather has also played a pivotal role in producer's decisions to grow a wheat crop in recent years. Dry conditions and extended cold weather well into spring have caused many growers to steer away from planting winter wheat.

Regardless of its decline in popularity, Arkansas still ranks in the top 10 of soft-red-winter-wheat producing states in the United States. In 2018, only 57,916 hectares were harvested for grain in Arkansas, a decrease of 14,479 hectares from 2017 (USDA-National Agricultural Statistics Service, 2018a). The number of hectares in Arkansas in 2018 accounted for only 1% of the 19.3 million wheat production hectares in the United States (USDA- National Agricultural Statistics Service, 2018c). Several types of wheat are grown across the United States, but Arkansas' most predominantly grown type of wheat is soft red winter wheat (Kelley, 2018). The primary use for Arkansas' soft red winter wheat is bakery flour that is used for products like cookies and pastries. Soft red winter wheat has a lower quantity of protein and gluten, which is ideal for producing baking flour (Bacon, 2016).

Winter wheat is typically grown as a dryland crop and is most often either drill-seeded or broadcast-seeded in the fall. While wheat is mostly planted on flat, even ground, in some distinct cases when a producer has poor drainage within a field, wheat can be planted on raised beds to prevent excessive water ponding and also aid in the establishment of the following crop, such as soybean, with little to no-tillage and ground preparation (Kelley, 2018). Wheat's typical cost of production is approximately $693.35 per hectare. Achieving a yield of 4,708 kg ha^{-1} results in a gross return of approximately $994.18, which makes growing wheat feasible. However, the Arkansas average yield is 3,497 kg ha^{-1}. This results in a gross return of only $738.53 per hectare, leaving the average Arkansas producer with a net return of less than $50 per hectare (USDA-National Agricultural Statistics Service, 2018a).

Double-Crop Soybean

Growing multiple crops in the same field within the same growing season, or double cropping, became popular in the early 1900s (Marra and Carlson, 1986). Today, approximately 60% of all wheat fields have a soybean crop planted into the residue immediately following harvest (USDA- National Agricultural Statistics Service, 2018d). Double-cropped soybean represents around 3% of the total soybean hectares planted.

Producers choose to double-crop due to the practice's many benefits. The year-round presence of ground cover reduces soil erosion (Holshouser, 2014). One of the greatest loss mechanisms for soil nutrients is from field runoff. Soil erosion can reduce soil organic matter (SOM) content as well. When erosion occurs, nutrients and beneficial soil organisms are washed away. One of the most effective methods of preventing soil erosion, and therefore avoiding the loss of SOM, plant essential nutrients, and beneficial soil organisms, is establishing and maintaining plant cover (Zuazo and Pleguezuelo, 2009). A common mistake many producers make is burning wheat residue following harvest. A study by Norman et al. (2016) in a long-term double-crop system found that burning decreased SOM. Instead, it is more beneficial to plant the following soybean crop directly into wheat stubble (Norman et al., 2016).

A double-crop system has the potential to make and save producers a lot of money. Growing two separate crops on the same land in the consecutive growing season can increase revenue for the year by selling an additional crop (Borchers et al., 2014). Wheat stubble aids producers in weed control costs, as the ground cover provides physical control of weeds by minimizing emergence. The ground cover also helps to keep the soil temperature low, as well as reduces the amount of light that reaches the soil. Both of these mechanisms help reduce the amount of weed-seed germination (Creamer et al., 1996). In a study performed by Amuri and others (2010) it was found that a no-tillage and no-burn double-crop system resulted in significant suppression of most weed species early in the soybean growing season Double-cropped soybean typically develop rapidly in their seedling stages. Because of rapid development, seedling insect pests and seedling diseases are usually less of a problem. Insecticide and fungicide seed treatments are most often unneeded, thus saving producers money (Holshouser, 2014).

In the years following the 1980s until the present, there has been a decline in the number of hectares that are being double-cropped to a winter wheat soybean rotation. Several factors have led to the decline, including weather, commodity prices, input costs, and timing. Timing is a crucial part of being able to have a successful double-cropping system. Many producers want to get their soybean planted as early as possible, but having to wait to harvest wheat to plant their soybean leaves a limited amount of time to get soybean established (Minor and Wiebold, 1998). Late soybean establishment can lead to shortened growing seasons for both crops, thus resulting in potentially lower yields (Borchers et al., 2014).

In 2005, a study was conducted in Stoneville, Mississippi to compare the yields of a double-crop system and a full-season soybean crop. The study showed that soybean following a wheat crop typically yielded 10 to 40% lower than the full-season soybean. However, Kyei-Boahen and Zhang reported that the wheat and soybean double-crop was more profitable than the full-season soybean crop alone, regardless of the lower soybean yields in the double-crop system. Profits from the wheat crop and the soybean profits together were greater than that of the full-season soybean crop alone (Kyei-Boahen and Zhang, 2006). Advances in technology, such as no-tillage equipment and early maturating soybean cultivars, can help to combat the restraint of shortened growing seasons and potentially increase yields of double-crop systems (Borchers et al., 2014).

The constraint of inadequate soil moisture for rapid soybean germination is also a major reason producers are shying away from double-cropping. If moisture is not present in the upper 5 cm of soil and soybean is unable to germinate, seeds can rot and lead to less-than-ideal stands and potentially requiring replanting. The poor establishment can lead a producer to have to abandon the double-crop for the season and leave fields fallow (Minor and Wiebold, 1998).

Crop rotation is an important aspect of successful crop production in today's world. Rotation is the practice of producing a wide variety of crops on one piece of land over time, to avoid the buildup of one particular pest or disease to a specific crop is. Double-cropping wheat and soybean are no different (Clark, 2007). Adding wheat into the mix essentially gives a producer an additional "offseason" crop in rotation with their typical summer crops. By doing so, a producer can further prevent the presence of corn or soybean diseases and pests.

Cover Crops

The USDA's definition of cover crop states cover crops are grasses, legumes, and other forbs that are planted for erosion control, improving soil structure, moisture, and nutrient content, increasing beneficial soil biota, suppressing weeds, providing habitat for beneficial predatory insects, facilitating crop pollinators, providing wildlife habitat, and as forage for farm animals. Furthermore, cover crops can provide energy savings both by adding N to the soil and making more soil nutrients available, thereby reducing the need to apply fertilizer (USDA-Natural Resources Conservation Service, 2018).

Cover crops are commonly sown between cash crops in a crop rotation, during fallow periods (Duiker, 2014). Cover crops can be grouped into two different subcategories based on when they are established and growing, summer and winter. Both winter and summer cover crops can provide the same benefits for producers but at different times of the year that best fit with the producer's primary cash crops. Potential benefits can include large amounts of above and below-ground biomass and improved SOM. The location and the benefits expected help to determine which cover crops should be utilized. Typically, in cool regions, winter cover crops compliment summer cash crops, whereas, in warmer regions, summer cover crops compliment winter cash crops. Although winter and summer cover crops are popular depending on region, either can be utilized in any climate depending on the niche that a producer needs to be filled (Snapp et al., 2005). Commonly planted winter cereals, such as oats (*Avena sativa*), triticale (*Triticosecale*), cereal rye (*Secale cereale*), and barley (*Hordeum vulgare*), are used, but broadleaves, like turnips (*Brassica rapa*), radishes (*Raphanus sativus* L.), clovers (*Trifolium*), or hairy vetch (*Vicia villosa* Roth), are also commonly utilized (Roberts et al., 2018). Commonly grown summer cover crops are Sudangrass (*Sorghum x drummondii*), pearl millet (*Pennisetum glaucum*), buckwheat (*Fagopyrum esculentum*), cowpea (*Vigna unguiculata*), and sunn hemp (*Crotalaria juncea*) (Penn State Extension, 2016).

Every grower has a specific need, and each cover crop provides a unique set of advantages the grower can utilize. Understanding the benefits that each cover crop provides is essential to achieve the goals of the producer. While they may or may not provide yield increases (Blanco-Canqui et al., 2012), cover crops have the potential to provide many benefits, including decreased erosional soil losses, improved soil health, increased weed suppression, building soil nutrient content, and preventing crusting (USDA-Natural Resources Conservation Service, 2018). Cost of production is the main concern among producers. If the cost outweighs the benefits, producers will likely shy away from a specific practice. Because cover crops are an added cost that often has no immediate monetary return, producers may be less inclined to grow cover crops. Determining cost-to-benefit ratios is important in helping a producer decide on a cover crop. To calculate these ratios, it is important to know the corresponding seeding rates and cost of the herbicide required to terminate each cover crop before planting the successive cash crop. It is also important to know all costs of production, such as tillage cost, to determine if cover crops should be utilized and which parts of production and cost could be affected.

For Arkansas, winter cover crops are ideally planted from September to mid-November (Roberts et al., 2018). Getting cover crops planted within the narrow window can sometimes be troublesome for producers due to the timing of cash-crop harvest. All of the dominant Arkansas summer cash crops can be harvested from August until November and the harvest window is significantly impacted by weather patterns. Some cash crops, like soybean, can even be harvested up until the end of November (USDA, 1997). Cover crops need to be sown between September to mid-November because planting date is critical to ensure maximum growth and benefits can be achieved (Roberts et al., 2018).

There are three common methods of planting cover crops: drill-seeding, broadcasting with incorporation, and aerial seeding. Drill-seeding is a popular method because many drills are designed to plant directly into large amounts of crop residue, allowing a producer to plant cover crops immediately following the harvest of a cash crop and drill-seeding typically yields the best stands with a lower total seed cost. Drill-seeding provides good seed to soil contact, leading to better, denser, and more uniform cover crop stands. Good cover crop establishment can result in increased biomass accumulation and, in turn, allow for greater weed suppression (Great Plains

Ag, 2019a). Drilled seeding rates are lower than the seeding rates for other methods (Roberts et al., 2018). This means that less seed per hectare will need to be planted and, because drill-seeding allows for a no-tillage system and requires no incorporation, fewer passes through the field are needed and optimum cover crop results are seen when a no-tillage management system is implemented (Roberts et al., 2018). A no-tillage system can save producers money on seed, fuel, as well as wear and tear on equipment.

Another seeding method of cover crops is broadcasting with incorporation. Although the broadcasting method can be accomplished in one pass through the field like the drilled-seeding method, it is accompanied by several challenges. Challenges can include inadequate seed-to-soil contact when seeding a cover crop mixture. Because of the varying seed sizes and amounts, broadcasting mixtures can be unevenly distributed and create nonuniform stands. It is also important to note that broadcasting requires an increased seeding rate of approximately 10 to 20% more than drilled seed, thus leading to greater seed costs (Great Plains Ag, 2019b).

The last cover-crop-seeding method is an aerial broadcast of seed. Aerial seeding can be utilized when the soil surface is too wet to use ground equipment, or if there is a need to be seeded quickly. Although potentially convenient, aerial seeding is riskier and more costly. Aerial seeding requires a seeding rate greater than that of both the drilled and the broadcast methods, which leads to greater cost per hectare, as well as the cost for the aerial application to sow the seed (USDA-Natural Resources Conservation Service, 2010). Seeding rates are important for establishing adequate stands and can depend not only on the seeding method but also on row spacing. For more narrow rows, a low seeding rate is recommended. For wider row spacing, a greater seeding rate is often recommended (Kladivko et al., 2014).

Although often beneficial, cover crops can raise concerns regarding possible increased pest pressures. It has been determined that cover-crop termination timing can decrease these pressures (Hoegenauer, 2019). It has also been shown that cover crops have the potential to control specific pests if the particular cover crop is not a host for the pest. This means that proper rotations and correct identification of pests are important to ensure the correct cover crop is chosen to interrupt the pest cycles (Reeves, 1994).

Potential cover crop benefits can be maximized by accurate termination timing. Early termination can decrease potential biomass accumulation, as well as nutrient accumulation of each species (Clark et al., 1997). The timing of cover crop termination can also affect the subsequent cash crop. Allowing for at least 1 to 2 weeks before planting the next crop can decrease soil water depletion, as well as decrease the effects of allelopathic chemicals released from the cover crops (Duiker and Curran, 2005).

Cereal Rye

Cereal rye (*Secale cereale*) is a winter cereal that is most often grown as a cover crop because of its winter hardiness (Ruffo et al., 2004), rapid growth, and the vegetative ground cover provided during the winter months (Bauer and Reeves, 1999). Cereal rye is well suited for a variety of soil textures and is a good choice for low-fertility fields (Roberts et al., 2018). It has been shown that cereal rye can produce greater amounts of allelochemicals under low-fertility conditions than other winter cereals (Bhowmik, 2003). Cereal rye is an annual, cool-season grass that grows with an upright plant structure. Cereal rye can provide excellent erosion prevention and weed suppression due to a large amount of aboveground biomass produced. The large amounts of biomass produced by cereal rye help to suppress weed growth by creating a physical barrier and shade weeds from sunlight. The root system of cereal rye aids in building soil structure, helping to relieve compacted soils, and is an excellent scavenger of nutrients such as N (Casey, 2012). By scavenging soil N and improving soil structure, N losses from runoff can be minimized.

For Arkansas, the optimal cereal rye planting period is from September to November and at a depth of 1.9 to 5.1 cm (Roberts et al., 2018). Seeding rates should range from 40 to 67 kg ha^{-1}, depending on the chosen planting method. Drill-seeded cereal rye planted at 45 kg ha^{-1} has a seed cost of approximately $30 per hectare. Grass cover crop termination can vary in price depending on the method, but can generally cost around $12 per hectare. This brings the total cost for a cereal rye cover crop to around $42 per hectare. The biomass left behind from a terminated cereal rye crop can create some difficulty when planting a subsequent cash crop. A no-tillage drill is often the chosen method of planting following a terminated cereal rye crop. No-tillage drills are designed to cut through stubble and hard soil surfaces, making these drills the perfect tool for planting into cover crop residue.

Scavenged N and other nutrients from the soil are stored and remain in the cover crop biomass following termination. Once terminated, cover crops begin decomposing and the rate of nutrient availability from the decomposing cover crop can vary greatly. The scavenged nutrients are returned to the soil and become available for the subsequent crop planted into the stubble, but the nutrient availability window can range from weeks to months depending on the nutrient and climatic conditions.

Although cereal rye is often utilized as a monoculture cover crop, it can also be combined with other cover crops, such as legumes, to maximize benefits and reduce the C:N ratio, which aids in cover crop decomposition. Legumes can generate their N via BNF. Once legumes produce N, cereal rye roots can scavenge the N from legumes, which can lead to greater amounts of biomass than might typically be produced in a cereal rye monoculture.

Black-seeded Oats

Black-seeded oats (*Avena sativa*) are a cool-season, winter annual in the Poaceae family (Dial, 2014) and are often planted as a cover crop in the rotation because of its ability to tiller well and produce large amounts of biomass, similar to that of cereal rye (USDA-Conservation Systems Research, 2005). Oat biomass production can range from 2,200 to 4,500 kg ha^{-1} (Roberts et al., 2018). The large amount of biomass that black-seeded oats produce is effective in out-competing and smothering weeds. Following the termination of black-seeded oats, the residue left behind releases allelopathic chemicals that can help suppress weed germination. Black-seeded oats can also be used as a catch crop, as they are excellent scavengers of excess nitrate in the soil (Clark, 2007). Oats perform well in water-logged soils, which can be very common in the poorly drained soils of the Arkansas delta region. Anaerobic soil conditions can also reduce populations of problematic root-knot nematode (*Meloidogyne* spp.) (Roberts et al., 2018). Oats can be planted during the September to November window and should be planted 1.3 to 3.8 cm deep. The recommended seeding rate for black-seeded oats ranges from 50 to 67 kg ha^{-1} (Roberts et al., 2018).

Drill-seeded oats planted at 56 kg ha^{-1} cost $46 per hectare for seed. The same herbicide used to terminate cereal rye can also be used to terminate black-seeded oats, resulting in a similar herbicide cost per hectare of $12, bringing cover crop cost a total of $58 per hectare

Barley

Barley (*Hordeum vulgare*) is a cool-season, winter annual cereal grain (Clark, 2007) of the Poaceae grass family (The Editors of Encyclopaedia Britannica, 2018b). Barley is an excellent, well-rounded cover crop, with good drought tolerance (Ullrich, 2011) that provides erosion protection, weed suppression, nutrient recycling, and SOM additions (Clark, 2007). Like most annual grasses, barley grows fast and produces substantial amounts of aboveground biomass (up to 1,345 kg ha^{-1}) (Jacobs, 2016). When planted as a winter cover crop, the deep, fibrous root system can effectively hold soil in place, prevent erosion (Clark, 2007) and scavenge excess nutrients in the soil. Scavenged nutrients are then stored in barley's aboveground biomass, which is slow to break down, and effective in adding organic matter to the soil. Barley's extensive aboveground biomass is also effective at shading and preventing weed growth. Similar to cereal rye and black-seeded oats, barley also suppresses weed growth by releasing allelopathic chemicals (Jacobs, 2016). Barley can be planted from September through November at a seeding depth of 1.9 to 5.1cm (Roberts, 2018). Barley has a seeding rate ranging from 40 to 67 kg ha^{-1}. The seed cost of barley is roughly $46 when drill seeded at 45 kg ha^{-1} and can be terminated with the same herbicide used to terminate other grass cover crop species which costs around $12 per hectare. The costs for barley production added together total $58 per hectare.

Barley can reduce populations of many crop pests, like leafhoppers (*Cicadellidae* spp.), armyworms (*Spodoptera* spp.), and root-knot nematodes. Barley can also act as a trap crop by providing an attractive environment for aphids (*Aphidoidea* spp.), which prevents the pest from damaging nearby or late cash crops (Roberts, 2018).

Austrian Winter Pea

Austrian winter peas (*Pisum sativum L.*) are a winter-hardy annual (Clark, 2007) legume of the Fabaceae family (The Editors of Encyclopaedia Britannica, 2018c), and are utilized as winter cover crops most often because of their rapid growth habit (Clark, 2007) and their ability to add large amounts of N to the soil (Pavek, 2012). Austrian winter pea can contribute 41 and 68 kg N ha^{-1} in a shortened growing season (Clark, 2007). Austrian winter peas can produce a large amount of biomass, up to 7,300 kg ha^{-1} (Roberts, 2018), but because of their low C:N ratio, the biomass breaks down quickly following termination, therefore, Austrian winter pea does not improve SOM rapidly and does not provide ground cover for a long period to aid with erosion prevention and weed suppression. In some cases, the combination of added N and rapid decomposition of Austrian winter pea residue can increase weed pressures.

Even with large amounts of biomass produced, Austrian winter pea provides little suppression of weeds, but varieties with long vines have shown to provide better weed control (Pavek, 2012). Austrian winter pea can be planted from September to November and from 3.8 to 7.6 cm deep (Roberts, 2018). Seeding rates for Austrian winter pea can range from 34 to 67 kg ha^{-1}. When drill-seeded at a seeding rate of 39 kg ha^{-1}, the cost per hectare is $44. Because Austrian winter pea is a legume, the herbicide that is required for the termination is different than the herbicide required for grass crops. The herbicide cost for terminating Austrian winter pea is around $50, which is greater than the cost of the grass herbicide, resulting in a total cost of $93 per hectare. One added benefit of Austrian winter pea is the N that is produced via BNF, which should be considered in the cost-to-benefit ratio. The N is typically available for the following cash crop and can be counted towards the cash crop’s season total N rate. When crediting N available from the Austrian winter pea biomass, the total cost per acre becomes much more reasonable.

Blue Lupin

Blue lupin (*Lupinus angustifolius L.*) is a cool-season annual legume (Clark, 2007). Like most legumes that are planted as cover crops, blue lupin can contribute N to the soil via BNF. Studies show that lupins are moderate N-fixing legumes, able to accumulate between 18 and 34 kg N ha^{-1}. Lupins are also able to accumulate "plant-unavailable" phosphorus (P) and store P in their biomass for the future use of subsequent crops as the residue decomposes.

Lupins have strong, deep taproots that can aerate and break up compacted soil. Greater plant densities of lupins are better for relieving compaction than lower densities. Added benefits of large plant densities include erosion protection, weed control, and crop disease suppression (University of California Division of Agriculture and Natural Resources, 2018).

Many fungal and viral plant diseases are problematic for the susceptible lupins. To prevent diseases from becoming a major problem, producers should avoid planting lupins in consecutive years and should consider rotating with a small-grain cover crop (Clark, 2007). When drill-seeded at a seeding rate of 45 kg ha^{-1}, blue lupin costs about $84 per hectare. The same herbicide used to terminate Austrian winter pea can be used to terminate blue lupin, which costs approximately $50 per hectare, bringing the total cost per hectare of blue lupin up to $134.

Crimson Clover

Crimson clover (*Trifolium incarnatum L.)* is a winter or summer annual legume that is commonly grown as a cover crop as a N source, soil builder, or to protect the soil against erosion (Clark, 2007). Crimson clover can contribute an average of between 14 and 27 kg N ha^{-1} when planted in the fall and terminated in the spring (MSU Extension, 2019). With relatively low biomass accumulation, crimson clover is less desirable for erosion and weed control compared to other legume cover crops (Roberts et al., 2018). Crimson clover is also excellent for scavenging mineralized N and preventing leaching into groundwater. The flowers of crimson clover produce nectar that attracts many beneficial pollinators and predatory insects that prey on crop pests (Clark, 2007). Clovers can be planted in September through mid-October at a depth of 0.6 to 1.2 cm (Roberts, 2018). Seeding rates for crimson clover can range from 11 to 22 kg ha $^{-1}$. Clover can establish a stand and can grow in poorly drained soil textures, where other legumes would not be able to thrive. Producers should take caution when planting clovers, however, as they have the potential to attract and increase pest problems like red-banded stink bugs (*Piezodorus guildinii*) (Roberts et al., 2018).

Seven-top Turnip

Seven-top turnip (*Brassica rapa L. var. rapa*) is a winter or summer annual of the Brassicaceae or mustard family (Young-Mathews, 2012). Seven-top turnip can prevent erosion, suppress weeds, scavenge nutrients, and alleviate soil compaction. Seven-top turnips do not provide as much ground cover as other brassicas, but they do create macro channels within the soil that increase water infiltration, in turn preventing excess water runoff. Some brassicas, including seven-top turnip, have large taproots that can reach depths of up to 1.8 m. The taproot allows them to scavenge nutrients from deep within the soil, and also makes them excellent for alleviating soil compaction, allowing subsequent crops to achieve better root growth into the soil (Clark, 2007). Brassicas can release chemicals that are toxic to plant pathogens, weeds, and insects (Haramoto and Gallandt, 2005). Mowing and incorporation into the soil maximize their suppression benefits as the decomposition of the plant residue is what releases these allelopathic chemicals (Clark, 2007). Turnips should be planted between August and mid-October at a depth of 0.6 to 1.9 cm deep. Seeding rates for turnips range from 9 to 22 kg ha^{-1} (Roberts, 2018). Brassicas have large root systems (Roberts et al., 2018) that allow them to scavenge nutrients from deep within the soil profile. Nitrogen scavenged from the soil is taken up into the cover crop and stored until termination. Once terminated, the cover crop begins gradually releasing the stored N. The stored N then becomes available for the next crop and is typically more available earlier in the season than N contained in winter cereal cover crop biomass (Gieske et al., 2016).

Cover Crop Blends

All of the cover crops previously mentioned have benefits when planted alone as a cover crop; however, many cover crop benefits can be improved when blended and planted with another cover crop. Sometimes, when grown together, cover crops will result in what is known as over-yielding. Over-yielding is when a mixture of plant species produces more biomass when grown together than when grown separately. Over-yielding is often maximized by combining a cover crop that reaches peak biomass production in the fall and does not over-winter and another that over-winters and reaches peak biomass in the spring.

Cover crops can influence C:N ratios of the soil, depending on the species or blend of species. Large C:N ratios, greater than 30, can cause the biomass from cover crops, such as cereals, to break down slowly, leading to a longer period of ground cover, but less immediately available nutrients to subsequent crops. Legumes typically have a lower C:N ratio, less than 20, which leads to faster biomass decomposition and nutrients being readily available to subsequent crops much sooner than that from cereals (Finney et al., 2016).

Mixtures of legumes and cereal cover crops can improve biodiversity within a crop field, can exploit the benefits of both crops, and improve upon some downfalls that each cover crop species present (Murrell et al., 2017). Austrian winter peas have biomass that breaks down quickly; therefore, planting peas with a cereal crop that breaks down slowly can help maintain surface residue for longer periods (Pavek, 2012). To maximize N accumulation for subsequent crops, a producer can mix an over-wintering legume with a grass cover crop, like black-seeded oats. The grass will scavenge for N in the soil, and will also take up the N that is fixed by the legume crop (Clark, 2007). For cover crops that are unable to suppress weeds alone, such as Austrian winter peas, a mixture with a cereal crop that provides excellent weed control, like cereal rye or black-seeded oats, can provide excellent weed suppression (Pavek, 2012).

There is a potential drawback of planting a cereal alone for scavenging N from the soil profile. A cereal crop, such as cereal rye, has a large C:N ratio and decomposes slowly. While a large C:N ratio can be great for weed suppression well into the spring, there is the potential for the cereal rye to immobilize any N or other nutrients that have been taken up during the winter months, rendering these scavenged nutrients unavailable to a subsequent cash crop. Immobilized, unavailable nutrients can severely hurt crop yield for a cash crop requiring a lot of N, like corn. It has been shown that a mixture of a legume cover crop and a cereal, like cereal rye, can lower the C:N ratio of both crops. The lower ratio has the potential to allow the cereal rye to be broken down more rapidly and can prevent or reduce the immobilization of scavenged N (Teasdale and Abdul-Baki, 1998).

Certain cover crops have different growth characteristics, allowing some to be able to out-compete others. Murrell et al. (2017) reported that when cereal rye is included in a cover crop mixture, it will out-compete the other crops present in the mixture. This can sometimes result in the benefits of these other cover crops being reduced (Murrell, et al., 2017). Oftentimes, the fall climate will play a significant role in dictating which cover crop species planted into a blend will ultimately dominate. When fall conditions following cover crop establishment are warm, mustards, such as turnip will tend to grow more rapidly and dominate the mixture, leading to reduced cereal growth. However, when cool conditions are present after establishment, the mustard species will have little growth and the winter cereals will tend to dominate the mixture.

Erosion

Soil erosion is defined as the removal of a field's topsoil by the natural physical forces of water and wind, or through forces associated with farming activities, such as tillage (Ritter, 2012). Soil erosion can be detrimental to crop producers because of the potential to cause soil physical, chemical, and biological properties to deteriorate. When the topsoil of a field is lost from the field via erosion, organic matter content, as well as the plant-essential nutrients contained within the soil, are removed as well. The effects of erosion occurring can be devastating to crop production, especially if it continues to occur year after year (Fageria et al., 2005).

Cover crops that produce large amounts of aboveground biomass are ideal for managing and preventing erosion in the offseason. Winter cereals, as well as some legumes, have the potential to produce large amounts of biomass (Roberts et al., 2015). Large amounts of aboveground biomass can shield the soil from rain drops, which prevents the detachment phase of erosional soil loss as well as slowing down water that is moving rapidly across the soil surface to help eliminate the transport phase of erosion by water (Sarrantonio, 2007). One constraint to growing cover crops is the timing of winter planting. A producer needs to get a cover crop planted early to allow for the adequate establishment of plant stands and growth of vegetative cover before winter rains begin (Roberts, 2015). Plant stand directly influences total vegetative cover or canopy coverage. A large plant stand within an area will have a large amount of vegetative cover or canopy coverage effectively reducing the amount of exposed soil surface. A vegetative cover prevents erosion by shielding the soil surface from the high-velocity impact of rain droplets (Shanks et al., 1998). Rain droplets hitting the soil surface can cause surface particles to be dislodged and transported. Once a particle is detached, it becomes an erosion hazard (Ram et al., 1960).

A vast amount of waters in the United States are impaired by sedimentation and turbidity and agriculture is a large contributor to these pollutants (Henley et al., 2000). Sedimentation is the deposition of sediment into a body of water and turbidity is the cloudy appearance in a body of water caused by sediments suspended in the water column (Rosado-Berrios and Bouldin, 2016). These pollutants can modify aquatic ecosystems and lead to extreme shifts in aquic ecological cycles (Henley et al., 2000). Cover crops offer an opportunity to mitigate these issues by helping to reduce runoff anywhere from 10 to 98%. Cover crops can reduce runoff in various ways, including slowing the velocity of runoff water, increasing water infiltration, runoff ponding and consequent increase in infiltration opportunity time, and improvement in soil structural properties. Cover crops can reduce sediment loss by 22 to 100% by providing a protective layer over the soil from raindrops. The protective layer can help prevent soil particles from being detached and removed with runoff water. Along with filtering runoff and preventing soil from being transported, cover crops can also provide stability to the soil via the roots that help hold soil in place and prevent soil particles from being detached. It has been often reported that as biomass increases, soil erosion decreases (Blanco-Canqui, 2018).

Soil Health

A major advantage of utilizing a cover crop is the potential to improve soil health. The USDA-NRCS defines soil health as, "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" (USDA-Natural Resources Conservation Service, 2019b). The NRCS also states that there are four methods to maximizing soil health: minimizing soil disturbance, maximizing biodiversity, maximizing soil cover, and maximizing living roots present in the soil. Soil health is influenced by the biological, physical, and chemical properties of soils and their interactions with one another.

For years, soil compaction has caused trouble for crop producers. Farm equipment, such as tractors and combines, apply pressure to the soil and create compacted areas. Plows and other tillage implements that continuously till at the same depth each year can create a plow layer (Blanco-Canqui, 2018). A plow layer is a form of compaction that hinders root growth of many crops, and can also impede water infiltration. Reduced water infiltration can increase the amount of erosion in a field as well (Duiker, 2004). Cover crops can aerate the soil and aerating the soil helps to reduce soil compaction and improve the structure and strength of the soil as well as increasing water infiltration (Myers, 2017). The extent to which a cover crop can alleviate compacted soils depends on the amount of belowground biomass it can produce. Cover crops like radishes (*Raphanus raphanistrum subsp. Sativus* L.), and other brassicas, that develop deep taproots can penetrate and break up compacted layers of soil, allowing for better subsequent root growth and water infiltration for future crops (Blanco-Canqui, 2018). Soybean roots can take advantage of the low-resistance pathways or channels left behind by the taproots following their decomposition. Soybean yields have shown to drastically increase following a mix of radish and cereal rye cover crops. The cereal rye's extensive aboveground biomass decomposes and results in a greater amount of surface soil moisture, while the radishes relieve compaction allowing soybean roots to be able to readily obtain soil moisture (Williams, 2004). Cover crops, especially legumes, feed many types of soil organisms, such as earthworms (*Lumbricina* spp.), by building soil C and SOM, which improves the biodiversity in farm fields (Myers, 2017). With aid from earthworms and other soil organisms, a water-insoluble protein known as glomalin is created (Sarrantonio, 2007). Glomalin helps bind soil aggregates together leading to stronger soil structure and more water-stable soil aggregates (Myers, 2017). Cover crops, in addition to most other plants, promote the abundance of beneficial mycorrhizal fungi in the soil. Mycorrhizal fungi have hyphae that penetrate through the soil and take in water and soil nutrients, which helps to feed current and subsequent plant roots. By promoting the production of glomalin and mycorrhizal fungi, cover crops can improve soil tilth as well as improve water infiltration and nutrient storage within the soil (Sarrantonio, 2007).

Cover crops produce C-based molecules from sunlight and carbon dioxide through photosynthesis, leading to a buildup of C present in the soil. The accumulation of C has many positive benefits for both soil physical and chemical properties. Though many soil microorganisms utilize C for survival, some of the soil C created from plants becomes humic substances, leading to a gradual increase in SOM (Myers, 2017). Large SOM contents can improve the soil's water-holding capacity, as well as improve the ability of the soil to bind plant-essential nutrients in the soil through increased cation exchange capacity (Sarrantonio, 2007). Cover crops contribute to better management of soil nutrients and help keep the soil covered, greatly reducing soil erosion and potential nutrient loss (Myers, 2017).

Weed Suppression

Problematic weeds, especially Palmer amaranth (*Amaranthus palmeri* S.), are a major source of yield loss for crop producers. Many weeds have evolved herbicide resistance due to extreme selection from over-reliance to specific, individual herbicides (Montgomery et al., 2017). An effective method of controlling herbicide-resistant weeds is through the use of cover crops. Cover crops are extremely effective in controlling weed problems, as they can out-compete weeds for water, sunlight, and essential plant nutrients (Baas, 2015). One of the most effective cover crops used for weed suppression is cereal rye. A cereal rye cover crop can provide between 65 and 99% control of common problem weeds in soybean, such as giant foxtail (*Setaria faberi*), common lambsquarters (*Chenopodium album*), and smooth pigweed (*Amaranthus hybridus*). The cereal rye cover crop alone can provide similar control of these in soybean as when a PRE- or POST-applied herbicide is used with no cover crop (DeVore et al., 2013). Other cover crops, such as wheat and barley, can help reduce weed densities by up to 90% (Rosario-Lebron et al., 2019).

Cover crops help control weeds by physical suppression from biomass or residue, direct competition, altering the environment, or from allelopathic chemicals. Physical suppression of weeds is achieved by cover crop species that produce large amounts of biomass, like cereal rye. Although weed control is species-specific (Teasdale, 1996), weed densities of palmer and other small-seeded broadleaves often decrease as cover crop biomass/residue increases (Webster et al., 2013). Cover crop species that typically provide adequate biomass accumulations for weed control are mustards, radishes (Holmes et al., 2014), and cereal rye (Teasdale, 1996). An additional benefit of increased cover crop biomass is direct competition with weed species. Cover crops alter the environment of potential weeds by out-competing weed seeds and seedlings for light. Preventing light from reaching weed seeds can inhibit germination and stop them from emerging (Rosario-Lebron et al., 2019). Cover crops can also modify the soil temperature and soil moisture making the area unfavorable for weed germination (Creamer et al., 1996). Cover crop competition with weeds not only provides the opportunity to reduce weed presence but also to diminish the soil seed bank over time (Holmes et al., 2014).

Certain cover crops can secrete what is known as allelopathic chemicals. Allelopathy is when a plant can produce chemicals that can harm the germination, growth, or development of another plant species (USDA-Natural Resources Conservation Service, 2016). Specific cover crop species, such as clover, oats, cereal rye, wheat, and other cereals, have shown to have allelopathic effects on other plants and can suppress their germination and growth (Rosario-Lebron et al., 2019). Many of these species are often grown together as a cover crop mix. Having multiple allelopathic chemicals can create a synergistic effect and suppress multiple weed species at once (Creamer et al., 1996).

Allelopathic cover crops can also suppress the germination and growth of cash crops as well, which is not desirable and can create some problems when attempting to incorporate cover crops into a crop rotation. Some crops are more tolerant of allelopathic chemicals than others and seed size plays a role in the susceptibility to allelopathy during germination. Soybean is more tolerable to the allelopathic chemicals produced by cereal rye than corn (USDA-Natural Resources Conservation Service, 2016). Cover crops are often terminated before planting a cash crop, preventing competition (Rosario-Lebron et al., 2019). Because these chemicals can be released from live or dead plants, it is important to terminate several weeks before planting the following cash crop (Bhowmik, 2003).

Nutrients

The three plant-essential macronutrients that are most often limiting in production fields are N, P, and K. It is important to understand how cover crops affect these nutrient cycles and their availability to subsequent crops (Maltais-Landry et al., 2014). The extent to which these nutrients are scavenged by cover crops is important for the proper management of fertilizers in the subsequent cash crop. Another important factor to consider is how cover crop residue management influences decomposition as this will be the controlling factor in how quickly N and P will be available to the subsequent crop.

Legume cover crops have the unique ability to fix their N when properly inoculated. Legumes can fix their N through the help of rhizobial bacteria in nodules on their roots (Sarrantonio, 2007). Common legume cover crops are Austrian winter pea, crimson clover, and hairy vetch. Austrian winter pea can produce a large amount of biomass and provide a large amount of N to the subsequent crop. Crimson clover can provide some N but can be difficult to establish (Roberts, 2015). Producers who are planning to grow a cash crop that requires a large amount of N can utilize a legume cover crop to reduce the amount of N inputs required (Seman-Varner et al., 2017).

Some grass cover crops, such as cereal rye or annual ryegrass (*Lolium multiflorum*), will scavenge for N in the soil that would otherwise leach down into tile drains or groundwater (Kladivko, 2011). Grass cover crops can have fibrous roots and stems, which break down and release nutrients slowly (Sarrantonio, 2007). This can be a benefit to a producer, as the plant material has the potential to temporarily tie up and prevent nutrients from being leached or lost by some other loss mechanism until a crop can take the nutrients up. Conversely, the rate at which the plant biomass decomposes will control the rate at which the nutrients are released and ultimately influences the timing of nutrient availability during the cash-crop growing season.

In addition to scavenging for N, grass crops also scavenge other nutrients, such as K and P. Steiner et al. (2012) reported that, when cover crops were placed into a rotation with cash crops, increased amounts of available K were present in the soil. It has also been shown that soil moisture can affect the amount of plant-available K in the soil (Zeng and Brown, 2000). Cover crops can increase water infiltration rates into the soil, which can, in turn, increase soil moisture. Increased soil moisture potentially allows for more plant-available K presence in the soil (Dabney et al., 2001). In a study performed by Maltais-Landry (2014), it was reported that P uptake was greater in cereal cover crops than in legume cover crops; however, cereals take longer than legumes to decompose. Slow decomposition leads to the gradual release of readily available P for the following crop due to large C:N tissue ratios that most winter cereals grown as cover crops might possess.

As aforementioned, erosion is a major issue facing producers. Nutrient loss within the removed topsoil is especially problematic. Studies have shown that up to 53% of P present in sand topsoil can be removed and 12% of P present in loam topsoil can be removed in deposited sediment from erosion (Chambers et al., 2000). A plant's most readily available source of K in the soil is dissolved in the soil solution (Prajapati, 2012). During a heavy rain event, soil solution containing plant-available K, and topsoil containing soil solution, can be removed and transported by erosion (Bertol et al., 2007). Cover crops that produce a large amount of aboveground biomass can cycle nutrients during rainy winter months, as well as shield the soil surface from the impacts of heavy rainfall, ultimately reducing the potential for nutrient losses via erosion and runoff (Baumhardt, et al., 2004). In a study testing various cover crop abilities to cycle nutrients, oilseed radish cycled normal amounts of N and K but showed a greater concentration of P than all other cover crops tested (Wang and Ngouajio, 2008).

Crusting

Crusting of the soil surface can happen when soil particles are dispersed, reoriented, dried, and desiccated (Duiker, 2017) resulting after heavy rains. Soil crusting typically occurs early in the growing season on freshly tilled soil, or in the fall and winter following the harvest of summer crops. Soil surface crusting is a major problem when it occurs after planting but before seedling emergence. Most of the time seedlings are unable to penetrate soil crust leading to significant reductions in plant stands, especially if there are no follow-up rains soon after crusting occurs (Magdoff and van Es, 2007). In severe cases, crops may need to be replanted if crusting is thick enough to reduce plant stands below the threshold required for maximal yield production. One of the most effective methods of preventing soil crusting is using cover crops to shield the soil surface from rain drop impact. Lower soil surface strength (crusting strength) is usually observed under winter cover crops. Reduced soil crusting is most likely the result of the vegetative cover preventing rain droplets from dispersing and reorganizing soil surface particles (Folorunso et al., 1992). A study performed by Baumhardt et al. (2004) reported that when rain drops are intercepted before making contact with the soil surface, a thinner crust was formed than when drops hit the soil surface directly. When choosing a cover crop to shield the soil surface from rain, the more aboveground biomass present, the better. Cover crops that can produce large amounts of aboveground biomass include cereals, such as cereal rye, black-seeded oats, and barley (Roberts et al., 2018). Vegetation that is produced from these crops can slow down the velocity of rainfall before its impact on the soil surface, therefore reducing the water's ability to disperse and reorient soil surface particles. Additionally, organic matter additions from cover crops help to increase soil aggregation, which, in turn, helps to prevent soil crusting (Folorunso et al., 1992). Another way that surface residue from cover crops helps to reduce crusting is by slowing the rate of evaporation from the soil profile. When large amounts of plant residues are retained on the soil surface, soil temperatures are generally decreased, which lowers evaporation from the soil surface and increases water retention. As the soil dries more slowly under cover crop or surface residues, there is less potential for crusting to occur.

In addition to utilizing cover crops to prevent the soil from crusting, studies have shown that tillage can have a major effect on the soil's potential to form a surface crust. Repeated tillage can result in soil surface degradation, allowing the soil to become more susceptible to crusting. Soil conservation methods, such as no-tillage practices, are recommended to avoid crusting occurrences (Rosa et al., 2017).

Study Objectives

This study examines a variety of cover crop species and their effect on soybean yield and partial returns. In addition, this study will compare soybean yields following cover crops and soybean yields following soft red winter wheat harvested for grain as a wheat soybean double-crop system. Other components of this study will also assess factors including aboveground biomass, and nutrient uptake of the cover crop species as well as stand establishment in the subsequent soybean crop. Soil organic matter and pH will also be used to evaluate overall soil health following three full rotations of each winter treatment.

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Chapter Two: Influence of Cover Crops on Soybean Yield and Partial Returns as an Alternative to Double-crop Soybean

Abstract

The number of hectares dedicated to winter wheat (*Triticum aestivum* L.) in the south has been trending downward for almost a decade, presenting an opportunity for producers to utilize alternatives in their soybean [*Glycine max* (L.) Merr.] rotations, such as winter cover crops. A study was established to compare cover crops to traditional cropping systems by determining the effect each had on a successive soybean crop and to examine partial economic returns. Cropping systems implemented were winter fallow, winter wheat, and seven cover crop treatments, including cereal rye (*Secale cereale*), black-seeded oat (*Avena sativa*), barley (*Hordeum vulgare*), Austrian winter pea (*Pisum sativum*), blue lupin (*Lupinus angustifolius*), Blend 1 (cereal rye, crimson clover [*Trifolium incarnatum*], seven-top turnip [*Brassica rapa*]), and Blend 2 (black-seeded oats and Austrian winter pea). The winter cropping system did not affect the soybean plant population (P = 0.3236). However, soybean grain yield differed among the different winter cropping systems (P = 0.0007). Each of the cover crop treatments resulted in statistically greater soybean yields than that of the winter wheat soybean double-crop system. Results indicate that soybean following a winter cover crop resulted in a greater partial return than soybean following winter fallow; however, the double-crop system had a partial return similar to the soybean following winter cover crops (P = 0.0002). The results of this study showed that winter cover crops can provide an adequate alternative to both winter fallow and traditional winter wheat soybean double-crop systems.

Introduction

Soybean is an essential row crop that accounts for over 50% of the land area cropped in Arkansas (USDA-National Agricultural Statistics Service, 2020a). Although a majority of soybean is grown in an annual rotation with rice (*Oryza sativa* L.), corn (*Zea mays* L.), and cotton (*Gossypium hirsutum*), a portion of soybean are grown in rotation with winter wheat (Ashlock et al., 2000). A winter wheat crop immediately followed by soybean is referred to as a double-crop system. Double-cropping was once popular among Arkansas producers because it allowed for increased profits from the harvest of two crops in one calendar year. At the height of popularity, double-crop hectares accounted for 16% of soybean hectares in the state, but have since declined and continue to trend downward. In the last decade, the area planted in winter wheat has decreased almost 90% (USDA- National Agricultural Statistics Service, 2020b). Reduced soybean yield due to late planting has been the major factor in the decline of the winter wheat soybean double-crop area. Although soybean can be planted until mid-July, research suggests that if soybean planting is delayed beyond May, there is a potential to see a yield reduction of 0.09 to 1.69% per day (Salmerón et al., 2016). Currently, the average harvest date for winter wheat is June 7 leaving a small planting window for the following soybean crop (Kelley et al., 2020). With delayed soybean planting date comes decreased returns, making the double-crop system less profitable than full-season soybean.

The decline of winter wheat area in Arkansas creates a niche for alternative crop rotations, such as winter annual cover crops that still allow for timely planting of a subsequent soybean cash crop. Although cover crops do not contribute additional revenue, they can provide invaluable soil and water conservation benefits plus physical and chemical additions to the soil when managed properly. Potential benefits to implementing cover crops into a rotation are increased nutrient cycling, biological diversity, soil organic matter (SOM), improved weed control, biological nitrogen (N) fixation, and reduced erosion (Wortman et al., 2012). Each of these factors is dependent upon the cover crop (legume, grass, etc.) as well as if it is a single species or a mixture of species.

Although many species of cover crops can provide the same benefits, each cover crop provides a unique contribution to a production system. Legume cover crops are unique in that they perform biological N fixation and can add N back to the soil. Adding a legume cover crop will result in a C:N ratio typically lower than 20, which leads to rapid decomposition and nutrient availability for a subsequent crop and the potential for reducing fertilizer-N inputs to the following crop (Wagger, 1989).

Grasses or cereals are known for high biomass production which provides excellent weed suppression and erosion control (Pavek, 2012). The C:N ratio of a grass cover crop is ordinarily greater than 30. The large C:N ratios observed by grasses leads to a slow decomposition rate allowing for a longer duration of ground cover. However, the slow decomposition rate of grasses does not allow for immediately available nutrients (primarily N and P) for a successive crop as they are often retained in the biomass until decomposed (Wagger, 1989).

Brassicas can alleviate soil compaction. Many species of brassicas have a taproot that can not only scavenge deeper into the soil profile for nutrients but act as deep tillage to reduce soil compaction and allow for increased water infiltration (Clark, 2007). Williams and Weil (2004) were able to monitor taproots from a forage radish (*Raphanus sativus* L.) to show that taproots can break through plow pans. These taproots then created an unobstructed path for water and roots of the following soybean crop once they began to break down and leave channels behind contributing to soil macroporosity.

Literature has shown that cover crop mixtures can help achieve multiple goals by utilizing the unique contributions of each species in the mixture. For example, using a cover crop like clover that fixes N but cannot fully suppress weeds can easily be remedied by adding a winter cereal to the mixture to maximize the benefits of both species. Choosing the appropriate species or mixture of species is vital. However, if not managed properly with the correct termination and tillage practices, the producer may see more damage than benefits. Although cereal rye achieves maximum biomass accumulation between Zadoks 70 and 85, the most effective termination is achieved between Zadoks 65 and 73. Allowing growth beyond this point may allow for seed production and possible volunteer issues as well as incomplete termination (Keene et al., 2017). Parr et al. (2011) reported that incomplete termination of a cover crop can lead to reduced yields resulting from the inadequate establishment of the cash crop. They also found that chemical termination with herbicides was more effective than terminating with a roller-crimper due to potential reseeding and germination of the cover crops.

Soybean has four yield determining factors: plants ha^{-1}, pods $plant^{-1}$, seeds pod^{-1}, and seed weight. Although it is optimal to have around 320,000 plants ha^{-1}, soybean is unique given its ability to adapt to a wide range of plant populations. Studies show soybean can optimize yield ranging from 30,000 to 500,000 plants ha^{-1}. The adaptability of the soybean crop comes from the ability to compensate via branching (Carpenter and Board, 1997a) and adjust individual plant yield (Carpenter and Board, 1997b). When plants per hectare are determined to be lower than recommended, soybean can produce greater branch dry matter leading to a greater number of pods and still achieving optimal yields (Carpenter and Board, 1997a). The reverse is also true. When plant populations are dense, less branching occurs which lowers the individual plant's yield, but is compensated by having a greater plant population. While soybean can compensate for plant population, getting too far away from optimum plant populations can lead to negative effects such as lodging in densely populated soybean and harvest issues due to low branching in sparsely populated fields (Basol et al., 2013).

In a no-tillage system, cover crop biomass can provide many benefits, but there are possible disadvantages to continual ground cover including a negatively affected stand establishment of the following cash crop. Biomass can physically obstruct a planter or drill resulting in poor seed-to-soil contact. Biomass can also affect soil moisture by keeping the soil too wet or drying the soil out. Growing cover crop water use can lead to a depletion of soil moisture needed for the germination of the subsequent crop (Reeves, 2004).

Although there is substantial evidence that cover crops have the potential to provide benefits to producers in the United States, there has been little research on cover crops within the Mid-south and their potential effect on a soybean crop in a no-tillage production system. A study was established to evaluate the effects of different cropping systems on stand establishment and yield of the subsequent soybean crop and identify the profit-maximizing cropping system. It was hypothesized that winter cover crops would not affect soybean establishment and have a positive effect on soybean yield when compared to soybean following winter fallow and winter wheat. Soybean following winter cover crops was hypothesized to have greater returns when compared to the traditional cropping systems of winter fallow and winter wheat.

Materials and Methods

Site Description

Field experiments were established at three University of Arkansas experiment stations to determine the effect different cropping systems had on the yield of a subsequent soybean crop. A typical Mid-south soybean crop is commonly grown on a silt loam soil and trial locations were chosen based on soil texture. The locations chosen were the Vegetable Research Station (VRS) near Kibler, AR on a silty clay loam which has 3.2% sand, 59.3% silt, and 37.5% clay. Pine Tree Research Station (PTRS) near Colt, AR on a silt loam which has a 1.1% sand, 77.3% silt, and 21.6% clay. Rohwer Research Station (RRS), near Rohwer, AR on a silt loam soil which has 6.5% sand, 78.9% silt and 14.9% clay. Soil textures were determined using soil particle size distribution using the hydrometer method (Huluka and Miller, 2014). The VRS trial was located in the western part of the state and the PTRS and RRS trials were located in the eastern part of the state with RRS being the southern-most trial location. There were four replications of each treatment at each study location, and nine site years of grain yield data were collected from 2018 to 2020.

Before the establishment of this study, fields were cropped to a rice-soybean rotation at PTRS, a soybean-wheat double-crop system at RRS, and vegetable-soybean rotation at VRS. Each field trial used traditional management practices such as conventional tillage at a depth of 10 cm. Once established, plots were managed using no-tillage production practices and kept in the same location to identify the potential cumulative effects of the crop rotations. Soybean seeding rate, irrigation, and pest management were implemented based on recommendations from the University of Arkansas System Division of Agriculture’s Cooperative Extension Service (Allen et al., 2000).

Fallow Management

A mixture of paraquat (841 g ha^{-1}) and metribuzin (210 g ha^{-1}) was used as a burndown to ensure a start-clean-stay-clean production system before planting soybean. After soybean harvest, plots were left fallow all winter to represent one of the traditional winter production practices in the Mid-south.

Cover Crop Management

Various winter cover crops were implemented in this study and included five single species and two blends. The single species cover crops included: Austrian winter pea, barley, black-seeded oats, blue lupin, and cereal rye. Blend 1 consisted of cereal rye, crimson clover, and seven-top turnip at 96:2:2 respectively. Blend 2 was a mixture of black-seeded oats and Austrian winter pea mixed at 50:50. Seeding rates and planting dates for cover crop and location are summarized in Table 2-1 and Table 2-2, respectively. Cover crops were flat-planted at VRS and PTRS with a plot size of 2.3 m wide and 43 m long with 19 cm row spacing. At RRS, cover crops were planted in nine rows spaced 15 cm apart atop raised beds that were used to aid in irrigation and for water drainage during the winter months. Cover crops were terminated at approximately early heading to allow for maximum biomass accumulation. Broadleaf species and cover crop blends were terminated using a mixture of paraquat (841 g ha^{-1}) and metribuzin (210 g ha^{-1}), while cereals were terminated using glyphosate (1,542 g ha^{-1}). According to University of Arkansas recommendations, the following soybean crop was planted 2 to 4 weeks after chemical termination to minimize pest issues (Roberts et al., 2020).

Winter Wheat Management

Winter wheat plots were established using modern, well-adapted winter wheat cultivars for the Mid-south including Armor ‘Lockdown’ (Winfield Solutions, Jonesboro, AR) in fall 2017 and Progeny ‘Turbo’ (Progeny Ag Products, Wynne, AR) in fall 2019. During fall 2018, a forage wheat cultivar was planted at each location but was not harvested for grain. Winter wheat planted for forage was drilled at a seeding rate of 45 kg ha^{-1}, and winter wheat planted for grain was drilled at a seeding rate of 112 kg ha^{-1}. The winter wheat for grain crop was managed using University of Arkansas Cooperative Extension Service guidelines (Johnson et al., 1999). Six N rates were applied in the spring at dormancy break and/or dormancy break +3 weeks to identify the optimal N rate. Nitrogen rates included 0, 34, 34 + 34, 50.5 + 50.5, 67.5 + 67.5, and 84 + 84 kg N ha^{-1}. All N was applied as urea (460 g N kg^{-1}) treated with Agrotain at a rate of 267 g active ingredient (a.i.) kg^{-1} (Koch Industries, Wichita, KS), a N-n-butyl thiophosphoric triamide (NBPT) urease inhibitor at a rate of 3.1 mL of Agrotain kg $urea^{-1}$.

Each winter wheat plot was 2.3-m wide by 10.6-m long. Winter wheat was grown until maturity when the middle seven rows were harvested with a small-plot combine. Yields were determined by adjusting grain moisture to 13% and reported as kg grain ha^{-1}. The yield associated with the yield maximizing N rate was the reported yield for that site year and the associated N rate was used in the partial cost analysis and therefore varied by site year.

Soybean Management

Soybean was drill seeded approximately 2 to 4 weeks after the termination of cover crops to break the green bridge per University of Arkansas recommendations (Roberts et al., 2020). Stand establishment counts were then taken approximately 30 days after planting (DAP) to evaluate the impact of winter cover crop treatment on soybean stand establishment and ensure proper plant populations were achieved to produce optimal yields.

At each location, soybean plots were established using no-tillage practices at a seeding rate of 370,500 seeds ha^{-1}, 2 to 4 weeks following cover crop termination of the winter cover crop treatments and as close to wheat harvest as possible in the double-crop treatments. The soybean cultivar P44A08L (Pioneer, Johnston, IA) was used in 2018, the cultivar Credenz 4222LL (BASF, Ludwigshafen, Germany) was used in 2019, and the cultivar P44A37L (Pioneer, Johnston, IA) was used in 2020. The soybean cultivars were chosen to represent high-yielding, locally adapted cultivars with herbicide-tolerant traits required to control summer annual weeds in an Arkansas no-tillage production system. Soybean was drill-seeded at PTRS (38-cm row spacing) and VRS (19-cm row spacing) locations. At RRS, soybean was no-tillage planted using a John Deere vacuum planter (Deere & Company, Moline, IL) with 97 cm row spacings. Soybean was managed using University of Arkansas Cooperative Extension Service guidelines (Allen et al., 2000) for irrigated soybean production. At PTRS, soybean was flat-planted and flood-irrigated. At VRS, soybean was flat-planted and irrigated with a lateral, overhead sprinkler system. At RRS, soybean was established on raised beds and furrow-irrigated as needed. For all locations, irrigation was applied as needed with a goal to begin irrigation around 3.8 cm of soil-water deficit (Tacker and Vories, 2000). At maturity, soybean was harvested using a small-plot combine, and yields were adjusted to 13% moisture and reported in kg grain ha^{-1}. Major agronomic activities and dates for cover crop, winter wheat, and soybean are presented in Table 2-2.

Stand Establishment

Stand counts were recorded from each plot following soybean emergence, approximately 30 DAP to determine if emergence and establishment were influenced by the winter cropping systems. Stand counts were recorded according to row spacing at each trial location. At VRS, soybean was planted at a 19 cm spacing, thus soybean in 52.5 row meters was recorded. A distance of 52.5 row meters represents 1/1,000 of a hectare, then the number was multiplied by 1,000 to determine the number of plants ha^{-1}. For 38 cm row spacing at PTRS, 1/1,000 of a hectare was represented by soybean present in 26.2 row meters, and 10.4 row meters were used for the RRS location.

Partial Economic Return Analysis

A partial economic budget was created for the nine winter treatments. Custom rates from Kansas State Department of Agriculture were used to determine production costs. Costs included a one disk pass for seed bed preparation in a conventional tillage system, planting of each crop (cover crop in a no-tillage system, soybean in both conventional tillage and a no-tillage system, and wheat), herbicide application, and fertilizer application costs (Kansas Department of Agriculture, 2020). Custom rates for one field cultivator pass and wheat harvest were determined using rates from the University of Missouri (Massey, 2020). Herbicide costs, fertilizer costs, and a bedder pass were determined using the enterprise budgets provided by the University of Arkansas (University of Arkansas System Division of Agriculture, Cooperative Extension Service, 2021). Seed prices were obtained from a local co-op, and soybean and wheat prices were based on a 10-year average (2011-2020) provided by the USDA (USDA- National Agricultural Statistics Service, 2019a, 2019b, 2021a, 2021b). All variable prices and partial costs for each treatment are presented in Table 2-3. All other costs including seed, pesticide, and harvest for soybean were not included under the assumption that they would all be the same for each treatment. Partial returns were calculated for each treatment using the following equation.

(1) PC = T+ WTP+ SC+ HC+ HA+ FC+ FA+ H+ SP

(2) PR= SR+WR- PC

PC is total \$ ha^{-1} of all variable inputs.

T is tillage cost in \$ ha^{-1} . T includes a disk, field cultivator, and bedder pass to represent a conventional tillage system.

WTP is the winter treatment planting cost in \$ ha^{-1}. WTP is determined by the cost of a conventional or no-tillage system.

SC is the seed cost in \$ ha^{-1}. SC is determined by multiplying the seeding rate (Table 2-1.) by \$ kg^{-1} and adding inoculation costs to legume cover crop treatments.

HC is herbicide cost in \$ ha^{-1} determined by adding the price of herbicide needed and cost of herbicide application.

FC is the fertilizer cost in \$ ha^{-1}. FC was calculated based on the yield maximizing N treatment at each location. N rate was multiplied by \$ of NBPT treated urea plus the cost of fertilizer application in \$ ha^{-1}.

H is the cost of winter wheat harvest in \$ ha^{-1}.

SP is the cost of planting soybean in \$ ha^{-1}. The cost of planting was determined based on a conventional or no-tillage system.

PR is the partial return in \$ ha^{-1}.

SR is the soybean return in \$ ha^{-1}. SR is determined by multiplying soybean yield (kg ha^{-1}) by the 10-year soybean market price.

WR is the winter wheat return in \$ ha^{-1}.

Data Analyses

All data were analyzed using PROC GLIMMIX in SAS 9.4 (SAS Institute, Cary, NC). Each response variable (soybean plant population, grain yield, and partial returns) was analyzed as a split-plot design with the whole-plot factor being site year and the treatments within site year being the split-plot factor. Each site year was set up as a randomized complete block design and a gamma distribution was used for each response variable. Variance components (Table 2-5) present the random effects of site year and block within site year.

Results and Discussion

Stand Establishment

Understanding the cumulative effects a crop rotation can have on a cash crop is crucial to effectively implementing a new cropping system. Literature has shown that biomass provided by winter cover crops can reduce germination in the following crop (Blanco-Canqui, 2015), but little to no research has been conducted on the effects that a winter cover crop can have on the germination or establishment of a subsequent soybean crop in an Arkansas no-tillage production system. It was reported in a similar study that soybean population establishment on a silt loam soil in eastern Arkansas was greater in a no-tillage system than in a conventional tillage system (Cordell et al., 2005). It was determined in this study that soybean populations were unaffected by the winter crop treatments evaluated ($P = .3236$). Although not significantly different from other treatments, the winter fallow plots resulted in numerically greater soybean populations than cover crop treatments. The average soybean population was 172,378 plants ha^{-1}, which is less than the number of plants required to maximize yield (247,000 plants ha^{-1}), but similar to plant populations that have shown to maximize profits (185,000 plants ha^{-1}) (Gaspar et al., 2020).

Because soybean is capable of overcoming low-density populations by producing more branches and pods plant^{-1}, the variation in plant population did not result in a significant grain yield difference among winter crop treatments (Carpenter and Board, 1997a). These results suggest that even with large biomass producing cover crops soybean can be easily and effectively established using cover crops and no-tillage production practices, even after several years of biomass accumulation and no-tillage production.

Soybean Grain Yield

Planting conditions played a crucial role in the timing in which all crops were established. Roberts et al. (2015) determined that fewer benefits were observed in a soybean crop following delayed-planted cover crops than following cover crops that are established in an optimal planting window. Because of this, it is imperative to establish winter cover crops in a timely matter, when conditions are favorable, to ensure the success of the subsequent soybean crop. In fall 2017, excessive rainfall of up to 45 cm (Table 2-7) during the optimal planting window for cover crops delayed planting and establishment into December at all locations. Suboptimal weather conditions proved to be an issue again in fall 2018. The planting of winter treatments at PTRS was delayed until the following spring, and winter treatments at RRS were unable to be planted due to the severity of the weather conditions. In fall 2019, optimal planting conditions occurred and timely planting of all winter treatments was achieved. Monthly precipitation is reported in Table 2-8 and indicates the precipitation patterns during the optimal planting windows can be highly variable and severely limit the planting of winter cover crops following previous crop harvest.

The planting date of both winter crops and cash crops can affect the success of the cropping system. The planting date of soybean following winter wheat can be largely dependent on weather conditions, wheat variety, wheat relative maturity, and wheat harvest date. Studies show that in Arkansas, a 1 to 2% yield decrease can occur for every day soybean planting is delayed past June 15. Throughout this study, there were four occurrences of soybean planting past June 15. Three of those instances were soybean following winter wheat. Soybean planted in the double-crop system was delayed due to the timing of wheat maturity and harvest date. In 2019, at VRS, soybean planting following cover crops was delayed till June 21 due to excessive precipitation.

Each cover crop treatment was chosen based on its potential to succeed in Arkansas' climate. Although most species survived Arkansas winters, blue lupin was not well suited. It was observed that in years and locations where blue lupin was planted in an optimal cover crop planting window from September to mid-November that blue lupin was unable to survive the winter and experienced winter kill. In fall 2018, excessive soil moisture did not permit timely planting of cover crops and at PTRS cover crops were not planted until spring 2019. This was the only site year in which a majority of the blue lupin survived until chemical termination. For this reason, it was expected that the blue lupin treatments would closely resemble that of the winter fallow treatment.

Soybean grain yield differed among the preceding winter cropping systems ($P = 0.0007$; Table 2-4). Soybean yields ranged from 1,009 to 5,649 kg ha^{-1} across the nine site years, and soybean grain yield averages by winter treatment are presented in Table 2-6. Each of the cover crops resulted in significantly greater grain yields than in the double-crop system. On average, cover crops increased soybean yield by almost 430 kg ha^{-1} compared to double-crop soybean. These findings support the results of Raper et al. (2019) who reported that, although soybean yield, which ranged from 2,605 to 4,250 kg ha^{-1}, it was unaffected by cover crop treatment. They also concluded that soybean following winter wheat harvested for grain yielded significantly less, ranging from 1,230 to 2,500 kg ha^{-1}, due to delayed soybean planting. Cover crops also yielded on average 220 kg ha^{-1} more than soybean following winter fallow. Even though each cover crop resulted in numerically greater-yielding soybean than the winter fallow treatment, Blend 1, Austrian winter pea, barley, and Blend 2 yielded significantly more than winter fallow. In a similar study, Chalise et al. (2019) reported that soybean following cover crops resulted in a 14% increase in soybean yield when compared to a no-cover-crop treatment. In the current study, on average, double-crop soybean yielded 207 kg ha^{-1} less than soybean following winter fallow despite no statistical differences among treatments which can be attributed to the later planting date of the double-crop soybean. The results from McCoy et al. (2003) indicated that soybean following a winter fallow yielded 50 to 60% more than double-crop soybean.

Partial Returns

Many studies have reported that implementing cover crops can provide benefits, such as reduced soil erosion and increased water infiltration. Although cover crop benefits seem promising, input costs are a driving factor in decisions made at the farm level, including the implementation of cover crops. Because cover crops are an added input cost, producers want assurance that they will positively influence yield or revenue. Cover crops may increase input costs that can often be offset by the accompanying reduction in tillage that is implemented in a cover-cropped system. Converting from conventional tillage to a no-tillage system would not only save a producer approximately $100 ha^{-1} in tillage costs but would also allow for optimal results from the cropping system (Roberts et al., 2018).

Due to the potential cover crops have in a no-tillage soybean rotation, it is imperative to analyze variable costs associated with each cropping system. To accurately represent the current management of these systems in Arkansas, a conventional tillage regime was used to calculate the partial returns for the double-crop system, as well as the winter fallow treatment.

Data analyses revealed that winter treatment significantly affected partial returns for cropping systems ($P = 0.0002$; Table 2-4). The winter fallow treatment returned \$165.21 ha^{-1} less than the double-crop system and, on average, \$110.52 ha^{-1} less than cover crop treatments. Previous research has shown that the double-crop system returned \$134 to 571 ha^{-1} more than soybean following a winter fallow on a clay loam (Kyei-Boahen and Zhang, 2006). Plastina et al. (2018) reported that cover crop implementation resulted in a profit change from a reduction of \$166 ha^{-1} to an increase of \$163 ha^{-1}, and Reddy (2001) reported that in Mississippi on a silt loam soil, compared to a no cover crop winter treatment, soybean following cover crops resulted in net negative returns. Although soybean grain yield following winter wheat was significantly lower than that of the cover-cropped soybean systems, winter wheat partial returns were approximately the same as that for the other cover crop treatments. Despite not being statistically different, the double-crop system returned, on average, \$54.69 ha^{-1} more than the cover crop treatments. Even though cover crop treatments did not result in increased returns over that of the double-crop system, cover crops still have the potential to provide benefits to the soil and future crops that winter wheat is unable to provide, especially if the winter wheat residue is burned or tilled in, which are common practices before soybean establishment.

Conclusions

To the best of our knowledge, this is the first comprehensive study of its kind over multiple years to identify the effects of various winter cropping systems on the yield and profitability of soybean in the Mid-south. The primary goal of this study was to determine if cover crops were a viable alternative to the traditional Arkansas winter practices implemented in a soybean rotation. Results indicate that winter cover crops do not have a significant effect on the establishment of the following soybean crop and have a positive influence on soybean yield and partial returns in a no-tillage system. Except for blue lupin, each cover crop treatment was just as profitable as the traditional double-crop system and more profitable than a winter fallow system in a no-tillage soybean production system.

Cover crops not only have an immediate impact of increasing soybean yield, but they also have the potential to provide long-term benefits. Management decisions, including proper cover crop or blend selection and correct and timely termination, are crucial to maximizing the success of implementing this new cropping system. These advantages make winter cover crops a promising alternative to both winter fallow and winter wheat-soybean, double-crop systems.

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Tables

Table 2-1. Seeding rate for each winter crop treatment

Crop Treatment	Drilled Seeding Rate
	------------------------kg ha^{-1}-----------------------
Austrian Winter Pea	39
Barley	45
Black-Seeded Oat	56
Blue Lupin	45
Cereal Rye	45
Blend 1	45
Blend 2	45
Winter Wheat	112
Fallow	-

Table 2-2. Management information and seeding dates for winter wheat, cover crops, and soybean for 2017-2020

Information	Pine Tree Research Station (PTRS)	Rohwer Research Station (RRS)	Vegetable Research Station (VRS)
Soil Series	Calloway silt loam	McGehee silt loam	Dardenelle Silt Loam
Soil Classification	Fine-silty, mixed, active, thermic Aquic Fraglossudalfs	Fine-silty, mixed, active, thermic Aeric Epiaqualfs	Fine-silty, mixed, superactive, thermic Typic Argiudolls
Cover Crop Row Spacing (cm)	19	15	19
Soybean Row Spacing (cm)	38	97	19
2018 Soybean Seeding Date following Cover Crops	April 19	May 1	June 12
2018 Soybean Seeding Date following Winter Wheat	June 18	May 25	July 3
2019 Soybean Seeding Date following Cover Crops	June 4	May 16	June 21
2019 Soybean Seeding Date following Winter Wheat	May 23	May 16	May 14
2020 Soybean Seeding Date following Cover Crops	June 29	May 13	June 2
2017 Winter Treatment Seeding Date	December 11	December 19	December 18
2018 Winter Treatment Seeding Date	March 19	DNP[a]	November 30
2019 Winter Treatment Seeding Date	October 18	October 24	October 18

a- Did not plant- DNP

Table 2-3. Variable costs for each treatment

Treatment	Tillage	Winter Planting	Seed	Herbicide	Fertilizer	Harvest	Soybean Planting	Partial Cost
	$ ha^{-1}$							
Austrian Winter Pea	-	40.77	43.24	32.47	-	-	43.12	159.60
Barley	-	40.77	35.58	20.58	-	-	43.12	140.05
Black-seeded Oat	-	40.77	39.54	20.58	-	-	43.12	144.01
Blue Lupin	-	40.77	67.95	32.47	-	-	43.12	184.31
Cereal Rye	-	40.77	33.61	20.58	-	-	43.12	138.08
Blend 1	-	40.77	37.60	32.47	-	-	43.12	153.96
Blend 2	-	40.77	44.48	32.47	-	-	43.12	160.84
Winter Wheat	99.16	40.10	54.36	130.52	72.89-84.98[a]	77.61	43.12	517.76-529.85[a]
Fallow	99.16	-	-	32.47	-	-	44.65	176.28

a- Indicates varying costs by location as impacted by differences in N fertilizer application rate required to maximize wheat grain yield.

Table 2-4. Abbreviated analysis of variance for soybean establishment, grain yield, and partial returns

	Soybean Establishment			
	NDF	DDF	F Ratio	P-Value
Winter Treatment	7	215.6	1.17	0.3236
	Grain Yield			
	NDF	DDF	F Ratio	P-Value
Winter Treatment	8	263.3	3.51	0.0007
	Partial Returns			
	NDF	DDF	F Ratio	P-Value
Winter Treatment	8	254.9	3.89	0.0002

Table 2-5. Variance components for soybean grain yield and partial returns

Soybean Grain Yield		
Effect	Estimate	Percent of Total
Site year	0.08567	83.26
Block (Site year)	0.000137	0.13
Residual	0.01709	16.61
Total	0.102897	100
Partial Returns		
Effect	Estimate	Percent of Total
Site year	0.1212	86.92
Block (Site year)	0.001409	1.01
Residual	0.01683	12.07
Total	0.139436	100
Soybean Establishment		
Effect	Estimate	Percent of Total
Site year	0.1917	78.23
Block (Site year)	0.002385	0.97
Residual	0.05097	20.8
Total	0.245055	100

Table 2-6. Soybean yield, partial returns, and soybean establishment as influenced by winter crop treatment

Treatment	Yield		Partial Returns		Soybean Establishment
	--- kg ha^{-1} ---		--- $ ha^{-1} ---		---plants ha^{-1}---
Austrian Winter Pea	3839	ab[a]	1334.34	a	163,535
Barley	3812	ab	1354.06	a	149,690
Black-seeded Oat	3762	abc	1341.68	a	158,589
Blue Lupin	3638	bc	1239.63	bc	171,216
Cereal Rye	3656	bc	1304.52	ab	157,606
Blend 1	3797	ab	1343.95	a	162,432
Blend 2	3906	a	1380.25	a	155,991
Fallow	3554	cd	1217.81	c	168,527
Winter Wheat	3346	d	1383.02	a	-

a- Means followed by the same letter within a column are not significantly different using $\alpha=0.05$.

Table 2-7. Monthly average precipitation data at the Vegetable Research Station (VRS), Pine Tree Research Station (PTRS), and the Rohwer Research Station (RRS) from 2017 to 2020 in cm.

Location	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
VRS	2017	4.98	5.41	13.49	22.63	17.15	15.57	18.16	22.91	M	8.51	3.02	7.59
	2018	8.23	20.47	18.24	7.39	10.64	8.59	7.90	13.94	6.76	9.93	6.07	12.19
	2019	9.47	13.54	4.88	12.78	22.71	23.14	16.21	27.79	19.46	18.47	13.36	.81
	2020	16.66	10.29	22.10	14.45	14.63	3.86	18.36	10.06	11.30	15.70	0.36	6.15
PTRS	2017	9.55	6.27	10.46	24.08	15.75	16.38	10.80	11.91	10.49	3.10	4.57	19.05
	2018	7.11	33.38	13.41	11.58	7.24	9.40	11.33	11.81	19.43	19.69	14.96	19.89
	2019	12.24	34.42	11.89	23.37	10.87	15.60	12.90	10.90	7.21	25.10	9.93	6.12
	2020	14.40	13.06	19.02	14.83	13.49	7.70	7.59	23.22	8.92	14.63	4.78	9.25
RRS	2017	9.17	6.30	6.35	17.30	17.42	11.84	7.26	20.68	11.20	11.20	3.38	19.61
	2018	7.21	37.31	18.69	20.19	9.12	6.43	5.82	22.68	4.80	11.61	17.12	20.22
	2019	13.5	32.77	13.31	29.92	17.35	15.32	14.68	3.51	10.16	22.91	9.86	12.55
	2020	14.68	18.26	25.10	12.62	3.56	18.31	10.74	13.67	19.10	3.03	3.25	19.25

Chapter Three: Biomass, Nutrient Uptake, and Soil Properties as Influenced by Winter Cover Crops

Abstract

Cover crops are recognized as an effective agronomic tool to improve soil health, water quality, and nutrient cycling. The efficiency of a cover crop to improve these aspects is influenced by species, biomass production, and management. A study was established to examine biomass accumulation, total aboveground nitrogen (N), phosphorus (P), and potassium (K) uptake as well as evaluate the effect of various winter treatments on water infiltration, pH, soil organic matter (SOM), and soil health in a no-tillage system. Eight winter treatments were included: cereal rye (*Secale cereale*), black-seeded oat (*Avena sativa*), barley (*Hordeum vulgare*), Austrian winter pea (*Pisum sativum*), blue lupin (*Lupinus angustifolius*), Blend 1 (cereal rye, crimson clover [*Trifolium incarnatum*], seven-top turnip [*Brassica rapa*]), Blend 2 (black-seeded oats and Austrian winter pea), and winter fallow. Each cover crop and cover crop blend produced up to three times as much aboveground biomass as the winter fallow treatment ($P < .0001$). Cover crops produced as much as 8,194 kg ha^{-1} in biomass and 107, 16.9, and 182 kg ha^{-1} of N, P, and K uptake, respectively. Overall water infiltration ($P = 0.0809$), SOM ($P = 0.3274$), and soil health calculation ($P = 0.4115$) were unaffected by cover crop treatments. Winter treatments had a small impact on soil pH with most winter treatments increasing soil pH throughout the study ($P = 0.0384$). The results of this study showed that biomass accumulation is crucial to achieving the benefits related to soil health and that several years of continuous management (>3) may be required to effectively change soil health related metrics.

Introduction

Cover crops are increasing in popularity among producers across the United States for their ability to improve soil quality, nutrient cycling, soil moisture, and more. A study performed by Hoegenauer et al. (2016) reported that effectively controlling factors such as soil erosion, nutrient runoff, weed suppression, and crusting is highly dependent upon sufficient cover crop biomass accumulation. Cover crop species can have a major effect on the amount of biomass produced (Wayman et al., 2015). Literature shows that grass crops, like cereal rye, produced more biomass than legumes (MacLaren et al., 2019). Accumulating adequate biomass can not only be directly affected by cover crop species, but also by cover crop planting and termination dates.

In Arkansas, the ideal planting window for winter cover crops is from September to mid-November (Roberts et al., 2018a). Cover crops can be planted late if weather conditions are unfavorable or planting could be delayed by late cash crop harvest (Duiker, 2014). In Arkansas, the average harvest date for corn (*Zea mays* L.) and rice (*Oryza sativa* L.) are September 18 and September 20, respectively, allowing ample time to establish winter cover crops; however, the average harvest date for soybean [*Glycine max* (L.) Merr.] is October 14, which could potentially push cover crop planting date beyond the optimal planting window (Kelly and Capps, 2020; Hardke and Mazzanti, 2020; Ross et al., 2020). When cover crop planting was delayed, a reduction in biomass was observed (Hayden et al., 2015). Timely termination is also imperative to a successful cover crop system. Clark et al. (1997) determined that delaying cover crop termination resulted in increased biomass and nutrient content; however, late termination can lead to delayed cash crop planting and result in a yield reduction (Borchers et al., 2014). Cover crops can be divided roughly into two categories: legumes and non-legumes. Non-legumes, such as cereal rye, can produce between 2,200 and 11,200 kg ha^{-1} of aboveground biomass (Roberts et al., 2018b), while Austrian winter pea has the potential of producing aboveground biomass up to 7,300 kg ha^{-1} (Roberts et al., 2018a).

Cover crops can influence the availability of nutrients for the next crop, and the amount of biomass produced by each cover crop directly affects the nutrients that the cover crop can recover from the soil. Nitrogen can be scavenged by many types of cover crops and is impacted by species demand and root architecture. Grass cover crops can use their fibrous root system to recover N that would otherwise leach out of the root zone. Other cover crops, such as legumes, can fix N to add to the soil while others can enhance the availability of P through the use of root/fungal associations with mycorrhizae. The cover crop root association with mycorrhizae aids in absorbing P, which can then be recycled back to the soil during decomposition of the cover crop (Sarrantonio, 2007). Comparatively, when a grass cover crop was introduced into the rotation, it was observed that the cover crop was able to extract K from non-exchangeable K pools, which could then be returned to the soil in a form available to the next crop. Because K exists as an ion in the soil, K is easily leached from cover crop residues and returned to the soil (Steiner et al., 2012).

Cover crops have the potential to assimilate nutrients from the soil and store nutrients until termination, where decomposition and mineralization begin and return nutrients to the soil. The mineralization process slowly releases nutrients that can then be taken up by a subsequent crop. Depending on cover crop type, the rate at which the plant residue mineralizes varies. Wagger (1989) reported that a cereal rye cover crop took longer to desiccate than a crimson clover cover crop, and the rye released N at a slower rate than crimson clover. At two weeks after desiccation, crimson clover had released 54 kg N ha^{-1}, whereas rye had only released 14 kg

N ha^{-1}. The release of nutrients can add nutrient credits to the soil and possibly result in the reduction of future fertilizer inputs and may also increase yields (Decker et al., 1994). Winter fallow can also affect the soil C:N ratio. Fallow seasons can reduce the organic-C and N in the soil because it does not replace soil organic matter (SOM) that has been lost via mineralization (Sainju et al., 2002). This is common in the United States since producers typically grow only one crop and leave fields fallow for the remainder of the year.

To maximize the benefits of cover cropping, it is important to keep crop residue on the soil surface for as long as possible and to minimize soil disturbance (Mazzonecini et al., 2011). Under a conventional tillage system, the residue becomes physically broken and maximum residue-soil contact is achieved resulting in an accelerated rate of mineralization (Henriksen and Breland, 2002). Because of this, cover crops are more beneficial in a no-tillage system. Increased surface residue coupled with a no-tillage system results in slower mineralization, decreased erosion and increased SOM (Aulakh et al., 1991).

Sapkota et al. (2012) reported that a no-tillage system resulted in increased SOM compared to a conventional tillage system. Soil organic matter can affect water infiltration rate as well as water-holding capacity. An increase in SOM will increase water-holding capacity and increase the water infiltration rate because SOM binds soil particles together into stable aggregates leading to greater pore space (Boyle et al., 1989). Without adequate infiltration rates, more instances of evaporation, runoff, and erosion are observed. While increased infiltration rates can be achieved by the addition of SOM, factors such as long-term tillage can have a negative impact.

Tillage can have positive short-term effects, including increased porosity, but long-term conventional tillage can lead to compaction and reduced aggregation, therefore, decreased infiltration. Tillage also leaves minimal soil surface residue coverage leading to erosion and crusting, which can also decrease infiltration (Hoorman et al., 2009). Bruce et al. (1992) reported that infiltration rate was 100% greater in no-tillage grain sorghum (*Sorghum bicolor* L.) than conventional tillage. Soil texture can also have an impact on water infiltration rates. Increasing clay content in soil can decrease infiltration due to small pore sizes. As pore sizes increase, infiltration also increases. While growing cover crops, their cumulative evapotranspiration can reduce available soil moisture at cash crop planting and create problems with the establishment of the subsequent cash crop and result in reduced yield (Dabney et al., 2001). After the termination of cover crops, surface residue traps water and aids in moisture retention, which can aid in the growth of cash crops, specifically during periods that the cash crop may normally be under drought stress (Fageria et al., 2005).

Current literature indicates that cover crops have the potential to provide benefits to producers in the United States, such as increased soil health, water-holding capacity, SOM, among other soil and water conservation advantages. However, much of the previous research has been conducted in areas that have established no-tillage production practices, climates that differ significantly, or other crop production practices (i.e., rainfed vs irrigated) that do not directly translate to the Mid-south. A study was conducted to evaluate the effects different cropping systems had on the aboveground cover crop biomass, aboveground nutrient uptake, SOM, soil health, and water infiltration. It was hypothesized that cover crops would produce more biomass and take up more nutrients than winter fallow treatments. Soil health, SOM, and water infiltrations were hypothesized to increase following cover crops when compared to winter fallow.

Materials and Methods

Site Description

Data on biomass accumulation and nutrient uptake of winter cover crops and winter cover crop blends were collected in 2019 and 2020. The locations for field experiments were the Vegetable Research Station (VRS) near Kibler, AR, the Pine Tree Research Station (PTRS) near Colt, AR, and at the Rohwer Research Station (RRS), near Rohwer, AR. Soil textures at each location were silty clay loam (3.2% sand, 59.3% silt, and 37.5% clay), silt loam (1.1% sand, 77.3% silt, and 21.6% clay), and silt loam (6.5% sand, 78.9% silt, and 14.9% clay) respectively, and were determined using soil particle size distribution using the hydrometer method (Huluka and Miller, 2014). Throughout this study, five site years of data were collected.

Before the establishment of this study, fields were cropped to soybean and managed with traditional management practices and conventional tillage to a 10 cm depth (Allen et al., 2000). For the duration of this research, plots were managed using no-tillage production practice.

Cover Crop Management

Winter cover crops were planted in plots 2.3 m wide by 43 m long with four replications of each treatment at each location. Cover crops were planted atop raised beds at RRS in nine rows at a 15 cm spacing. Raised beds were utilized at RRS to assist in irrigation as well as ensuring proper drainage during winter months. Cover crops were flat-planted at VRS and PTRS with 19 cm row spacing. At each location five single species, two blends, and a winter fallow were established for evaluation. The single-species cover crops included: Austrian winter pea, barley, black-seeded oats, blue lupin, and cereal rye. Blend 1 consisted of cereal rye, crimson clover, and seven-top turnip at 96:2:2, respectively. Blend 2 was a mixture of black-seeded oats and Austrian winter pea mixed at 50:50. Winter treatments were established at the seeding rates listed in Table 3-1. Cover crops were grown until each reached early heading stages for winter cereals when they were chemically terminated. Broadleaf-species cover crop blends and winter fallow plots were terminated using a mixture of paraquat (841 g ha^{-1}) and metribuzin (210 g ha^{-1}), while cereals were terminated using glyphosate (1,542 g ha^{-1}). Soybean was planted each season as the summer cash crop and was managed using University of Arkansas Cooperative Extension Service guidelines (Allen et al., 2000) for irrigated soybean production. At PTRS, soybean was flat-planted and flood-irrigated. VRS, soybean was flat-planted and irrigated with a lateral, overhead sprinkler system. RRS, soybean was established on the raised beds and furrow-irrigated as needed with the goal to trigger irrigation around 3.8 cm of soil-water deficit (Tacker and Vories, 2000). To reduce potential pest problems, the soybean crop was planted 2 to 4 weeks after chemical termination. The planting and sampling dates of each cover crop treatment at each location are presented in Table 3-2.

Aboveground Biomass Accumulation

Cover crop aboveground biomass samples were collected on the day of or the day before the chemical termination of each cover crop. All cover crop plants were sampled from a 1 m length of a row at the soil level with a hand sickle. In the winter fallow treatment, a sample area of 1 m by 0.1905 m was collected from the growing plants at the soil level with a hand sickle. Each sample was then dried in a forced-air oven at 60° C for a minimum of 14 d and weighed. To determine the amount of dry matter that was produced, dry weight from each treatment was divided by the sample area and extrapolated to kg ha^{-1}.

Aboveground Nutrient Uptake

Once samples for biomass accumulation were weighed, they were ground to pass through a 2 mm sieve and submitted to the University of Arkansas Agricultural Diagnostic Lab (Fayetteville, AR) for analysis. Samples were analyzed for total nitrogen (TN) using automated dry combustion (Nelson and Sommers, 1996) and P and K using HNO_3 digestion (Jones, 1991) and a Spectro Arcos ICP (SPECTRO Analytical Instruments GmbH, Germany). Aboveground nutrient uptake of N, P, and K (kg ha^{-1}) was calculated by multiplying nutrient concentrations by the respective aboveground dry matter for each cover crop treatment. Because no fertilizer applications were made, it was assumed that all nutrients quantified in the aboveground biomass were residual plant-available soil nutrients.

Soil Samples

Initial composite soil samples were collected from each study location in 2017 from the top 10 cm. Samples were collected from at least three locations within a rep and composited. Final soil samples were collected in the spring of 2021, following three full rotations of each cropping system. One composite soil sample was collected from each cover crop plot also at a depth of 0- to-10 cm. Soil samples were submitted to Ward Laboratories Inc. (Kearney, NE) for analysis. Samples were analyzed using the Haney Test (Ward Laboratories Inc., 2021) for soil pH using a 1:1 soil:water ratio (Sikora, 2006), soil organic matter (SOM) concentration via loss-on-ignition (Zhang and Wang, 2014), and a soil health calculation (Haney et al., 2008). The soil health calculation uses soil respiration (1-day CO_2-C), water-extractable organic C (WEOC), water-extractable organic N (WEON), and organic C: organic N ratio according to Haney et al. (2008) to produce a value 0 to 50 that represents the overall health score of a soil. A score of 7 is considered good, but the goal is to use the recommendations from the Haney Test to increase soil health scores over time (Ward Laboratories Inc., 2021). Baseline data from 2017 indicates that pH at PTRS, VRS, and RRS was 7.3, 7.7, and 6.6, SOM concentration was 3.0, 1.7, and 1.8, and the soil health calculation was 12.5, 8.6, and 17.6 respectively. Due to differences in the baseline soil property data at each location, the change in soil pH, SOM, and the soil health calculation was calculated. Data from the final sampling time was subtracted from the initial sample data (baseline) from each respective location to find the change after three years of each cropping system.

Water Infiltration

One infiltration reading was collected from a random location in each cover crop plot at the VRS using the falling head method (Desrochers et al., 2019). For each infiltration location, the residue was removed from the measurement area and a double-ring infiltrometer (model IN7-W, Turf-Tec International, Tallahassee, FL) was placed atop bare soil and tamped to a 2 cm depth. After installation, a Theta Probe (model ML2x, Dynamax, Inc., Houston, TX) was used in three to four areas in the outer ring to measure volumetric water content. A ruler was placed in the inner ring to observe changes in water levels. To begin infiltration readings, the outer ring was filled with water first followed by the inner ring. Immediately after the inner ring was filled, the height of the water in the inner ring was recorded to represent the initial height at time 0. Readings at 1, 2, 3, 4, 5, 8, 10, 12, 15, 18, and 20 minutes were also taken to determine the rate of infiltration. If all water infiltrated before the 20 minutes had expired, the time in which all water had infiltrated was recorded and used to calculate the overall infiltration rate in mm min^{-1} by dividing total mm by 20 minutes.

Data Analyses

Using PROC GLIMMIX in SAS 9.4, (SAS Institute, Cary, NC) biomass accumulation, N, P, K nutrient uptake, and net changes in pH, SOM, and soil health calculations were analyzed as a split-plot design. The whole plot factor is the site year and treatment within site year is the split-plot factor. Each site year was set up as a randomized complete block design with four blocks. A gamma distribution was used for each response variable analyzed except for SOM in which a beta distribution was used because SOM is a concentration. Random effects for each experiment are listed in Tables 3-5. Overall water infiltration rate was analyzed as a randomized complete block design with block as a random effect and winter crop treatment as a fixed effect.

Results and Discussion

Aboveground Biomass Accumulation

Weather conditions can influence winter cover crop planting dates, which can directly affect the amount of biomass each cover crop species can produce before termination. Due to excessive precipitation, up to 55 cm during optimal cover crop planting window, establishing cover crops in the fall of 2018 was a challenge. While it is ideal to establish cover crops in Arkansas from September to mid-November, cover crop planting at PTRS was delayed until spring 2019 and, at RRS, cover crops were unable to be established. Because of this delay, the lowest biomass accumulation for the five site years was observed at the PTRS location in 2019 with a range of 211 kg ha^{-1} to 1,364 kg ha^{-1}, whereas cover crops at VRS, which were established in fall 2018 and sampled in spring 2019, had biomass production that ranged from 1,324 kg ha^{-1} to 8,195 kg ha^{-1}.

Although each cover crop species was selected for its ability to thrive in Arkansas' climate, it was observed that across different years and environments most of the blue lupin was winter-killed at each location, excluding PTRS 2019 when cover crops weren't planted until spring. Because of this, each blue lupin plot was primarily observed to be winter weeds. Species that experience winter kill can have high fall productivity, which can provide some benefits, but not as many as when cover crops can survive the winter and continue to grow into the spring. Achieving maximum cover crop biomass will help to maximize potential benefits; therefore, planting adapted varieties that can be established in the fall and protect the soil through the winter is imperative (Finney et al., 2016).

A winter fallow treatment was included in the biomass study to represent the biomass of common winter weeds that grew at each location, which is frequently used in conventional tillage cropping systems in the Mid-south (Henry et al., 2008). Over the five site years, cover crop biomass collected at the time of termination was as large as 8,195 kg ha^{-1}. Each cover crop and cover crop blend, excluding blue lupin, produced more biomass than winter fallow, and with the combination of blue lupin and winter weeds, the blue lupin treatments produced more biomass than the winter fallow ($P<.0001$; Table 3-3). Although biomass from Blend 2 (black-seeded oats and Austrian winter pea) was only larger than barley, blue lupin, and winter fallow cover crop treatments, Blend 2 produced the most aboveground biomass, with a mean of 2,300 kg ha^{-1} produced across all environments (Table 3-4). Though literature shows that cereal grain cover crops, such as cereal rye or oats, have the potential to produce more biomass than legume cover crops (Chen et al., 2004), this study revealed there was no clear cover crop type that produced consistently more biomass across the environments investigated. In Mid-south production systems where residual soil N is low (<15 mg N kg^{-1}) legume cover crops or blends that contain legumes may perform as well or better than winter cereals which may be hindered by the lack of plant-available soil N.

Aboveground Nitrogen Uptake

Because previous research has shown that cover crops can reduce nutrient leaching (Aronsson and Torstensson, 1998), and potentially provide nutrient credits to the soil, it is important to measure the nutrient uptake of each cover crop (Kuo and Jellum, 2002). Nutrient uptake was highly influenced by species and the total aboveground biomass accumulated for each monoculture and blend and was similar to the results presented by Wayman et al. (2014). Because of this, the amount of N each treatment recovered followed a similar trend to that of biomass production. Generally, environments yielding lower amounts of biomass (PTRS19) resulted in less N uptake, and environments yielding large amounts of biomass (VRS19) resulted in larger N uptake. Blue lupin was expected to have similar N uptake to that of fallow due to winter kill and considering that winter weeds were the dominant species in the blue lupin plots.

Overall, N uptake ranged from 4.2 to 107.4 kg N ha^{-1}. The monoculture of Austrian winter pea, which had one of the largest biomass amounts, had significantly more N (42.4 kg N ha^{-1}) than all other treatments ($P<000.1$; Table 3-3), except for cover crop Blend 2, which was expected due to Blend 2 also containing 50% Austrian winter pea. Cover crop blend 1 and 2, with an average of 23.2 and 30.3 kg N ha^{-1}, respectively, had more N uptake than barley, blue lupin, and the fallow treatment. Means are presented in Table 3-4. Research suggests that legumes may contribute to the N uptake of a non-legume in a cover crop mixture, thus increasing the aboveground N uptake of all species in the blend (Jensen, 1996). Each of the non-legume monocultures (i.e., cereal rye, black-seeded oat, and barley) had similar amounts of N uptake and were significantly lower than single-species or blend treatments that contained legumes.

Cover crops are typically terminated within 2 to 4 weeks of planting the succesive cash crop and begin the decomposition and mineralization or immobilization processes. The speed at which the mineralization process takes place can play a major role in the availability of N to subsequent crops. Cereal rye and similar species have slow decomposition rates and gradual N release, while legumes have rapid decomposition rates and a quick N release (Sievers and Cook, 2018). Based on the results of this study, Austrian winter pea performed the best, accumulating a large amount of N in aboveground biomass. Our results indicate that Austrian winter pea is a good fit for Mid-south production systems as a winter legume cover crop either as a single species or as part of a blend.

Aboveground Phosphorus Uptake

According to Maltais-Landry (2014), cereal cover crops tend to take up larger amounts of P than legume cover crops. The results of this study indicated that, excluding blue lupin, there were no differences in the aboveground P uptake between monoculture cereal crops and monoculture legume cover crops ($P<.0001$; Table 3-3). Due to varying cold tolerances of each cover crop species, most were well-suited for Arkansas' winter climate, with blue lupin being the exception. Winter-kill of the lupin resulted in reduced biomass and a large percentage of each plot covered in winter weeds, leading to minimal P uptake. Across all site years, P recovery ranged from .58 to 16.7 kg P ha^{-1} with all cover crops taking up more P than blue lupin and the fallow treatment. Although not statistically different from other cover crop treatments, except the fallow, cereal rye, and blue lupin, Blend 2 resulted in the largest P uptake in the aboveground biomass (Table 3-4). The large P uptake may be a direct influence of the large amount of biomass accumulation Blend 2 was able to achieve, but also indicates that Blend 2 is a viable option for Mid-south producers.

Aboveground Potassium Uptake

Aboveground K uptake varied by cover crop treatment from 4.1 to 182.2 kg K ha^{-1}. Because of the varying amount of biomass accumulated by each cover crop treatment, K recovery was also variable. Treatments with large amounts of aboveground biomass accumulation took up more K than treatments with lower biomass production. Comparing a large biomass treatment such as Blend 2, to the winter fallow, Blend 2 had four times as much K (36.1 kg K ha^{-1}) uptake as the winter weeds that grew in the winter fallow plots (9.1 kg K ha^{-1}). Blend 2 had significantly more K uptake than all other treatments, except for black-seeded oat, which was expected due to blend 2 consisting of 50% black-seeded oat ($P<.0001$; Table 3-3). All monocultures and blends had more K uptake than blue lupin and fallow treatments, which was expected due to the winter-kill of blue lupin. Means for each treatment are presented in Table 3-4.

Differences in aboveground K uptake among treatments may also be influenced by root exploration of the various crops. Potassium is luxury consumed by plants and will be taken up regardless of need when there is plant-available K in the soil and is expected to be larger than residual soil N. Cover crop treatments that resulted in more biomass may have also explored more of the soil profile resulting in greater total aboveground K uptake.

Water Infiltration

Due to an excessive amount of precipitation, water infiltration measurements could only be collected at the VRS location in October 2020, following three full rotations of soybean and winter cover crop. It was expected that infiltration would be increased in winter cover crop treatments compared to winter fallow treatments. In a similar study, Desrochers et al. (2019)

reported that a no-tillage system on a silt loam soil in eastern Arkansas positively affected infiltration when compared to conventional tillage. At the VRS location, soil water content were right around soil saturation, but a large number of cracks (approximately 10%) due to the shrink swell nature of the clay soil which led to preferential flow were observed in each plot. Because of the cracks, it was expected that the preferential flow would have an impact on the infiltration rate; however, there were no differences among the treatments (P = 0.0806). Infiltration rates ranged from 0.05 mm min^{-1} to 6.67 mm min^{-1}.

Soil pH

Previous research has concluded that cover crop type can affect soil pH differently. Legumes tend to decrease the soil pH compared to other cover crops such as cereal rye (Reddy et al., 2003; Maltais-Landry, 2015; Hargrove, 1986), but Mbuthia et al. (2015) reported that cover crops did not affect soil pH. Results of this study indicate, that across all locations, each cover crop treatment excluding the black-seeded oat treatment were similar and resulted in a 0.4 unit increase in soil pH over the 3 years of the study. (P = 0.0384; Table 3-3), The black-seeded oat treatments yielded the smallest rise in soil pH which was a 0.2 unit increase and significantly smaller than all treatments except winter fallow. These results indicate that there was no clear trend among cover crop types and change in pH but soil pH may have increased due to the use of alkaline irrigation water (Morgan and Graham, 2019) which is a common occurance in the row crop delta region of Arkansas where two of these trials were located. The effect that cover crops have on soil pH is important to understand because pH can affect nutrient availability for the following cash crop, where the optimum soil pH range for soybean in Arkansas is 6.0 to 6.5 (Slaton et al., 2013). Generally, when soils have a high soil pH, trace element deficiencies are observed, whereas macronutrient deficiencies, especially basic cations, are typically observed in strongly acidic soils.

Soil Organic Matter

Literature indicates that the addition of cover crop residues increases SOM (Peterson et al., 1998; Hendrix et al., 1998) and that no-tillage systems also increase SOM, which can be attributed to plant residues decaying more slowly due to lack of incorporation (Nyakatawa et al., 2001). In a similar study, Norman et al. (2015) reported that over the first 6 years of continuous no-tillage production on a silt loam soil in eastern Arkansas, SOM increased at a rate of 0.097 kg M^{-2} yr^{-1} (Norman et al., 2015). After three full rotations of each cropping system, it was expected that an increase in SOM would be observed. With final SOM concentrations ranging from 0.8 to 3.2% across locations, statistical analyses indicated there were no net differences in SOM concentrations among winter cropping treatments ($P = 0.3274$; Table 3-3). Numerically, black-seeded oat had the largest change in SOM concentration from 2017 to 2021 (+0.49) whereas the single-species legume treatments, Austrian winter pea (+0.28) and blue lupin (+0.29), resulted in the smallest change in SOM concentration. Typically, increases in SOM are related to total biomass accumulation and the C:N ratio of the residues. The black-seeded oat treatment produced some of the larger aboveground biomass values and lowest aboveground N uptakes suggesting that the residue had a larger C:N ratio that slowed residue decomposition and led to increases in SOM. The treatment with the largest aboveground biomass was Blend 2, which contained black-seeded oat, but also contained the legume Austrian winter pea and had one of the larger total N uptake amounts measured. Because each treatment including the winter fallow resulted in an increase in SOM, it can be concluded that no-tillage had a positive effect on SOM accumulation (Norman et al., 2015). These results further support the idea that biomass production alone does not lead to increases in SOM, but rather a combination of biomass production, C:N ratio, and tillage system which dictates residue decomposition rates. The continuation of this trial will be pivotal to determine if significant increases in SOM can be observed with long-term cover cropping and no-tillage management.

Soil Health Calculation

The results of this study indicated that there were no differences in change in soil health score among treatments across all locations ($P = 0.4115$; Table 3-3), which was similar to Singh et al. (2020) who found that the soil health calculation (SHC) for cover crops in a no-tillage system did not differ from the no-tillage fallow treatments. Soil health calculation scores did increase numerically after three full rotations of each cropping system resulting in scores above 7.0 which is the desired number for "good" soil (Ward Laboratories Inc., 2021). While cover crops may not have a significant effect on soil health score in the short term, other studies suggest that duration can be a major factor in improving soil health (Nouri et al., 2018). If increasing the duration of a management system has a positive impact on soil health, it is expected that the continued implementation of winter cover crop treatments and no-tillage management practices will continue to increase soil health scores.

Conclusions

The objective of this research was to evaluate cover crop suitable for an Arkansas production system to determine which cover crop provided potential benefits. While infiltration measurements did not reveal any effect of cover crops on water infiltration, results indicated that cover crop treatments, such as Blend 2, Austrian winter pea, and black-seeded oat, provided some of the largest amounts of biomass, with some treatments producing up to four times as much biomass compared to fallow. The treatments that produced the most biomass also had the largest N, P, and K uptake. Although the soil health calculations did not consistently or statistically increase across all locations during this study, each treatment resulted in a “good” score from the implementation of a no-tillage system. Continuing no-tillage for years to come has the potential to increase overall soil health.

The results of this study demonstrated that blue lupin is not a good fit for planting as a winter cover crop in Arkansas, but each of the other cover crops and cover crop blends are well suited for Arkansas’ environment and have the potential to provide immediate and long-term benefits in a no-tillage system. To maximize success, it is important to choose the cover crop that best fits the needs of the producer and to plant on time to ensure adequate biomass production and maximum benefits.

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Tables

Table 3-1. Seeding rate for each winter crop treatment included in the study.

Cover Crop Treatment	Drilled Seeding Rate
	------------------------kg ha $^{-1}$----------------------
Austrian Winter Pea	39
Barley	45
Black-Seeded Oat	56
Blue Lupin	45
Cereal Rye	45
Blend 1	45
Blend 2	45
Fallow	-

Table 3-2. Cover crop planting and aboveground biomass sampling dates at each location.

	Pine Tree Research Station (PTRS)	Rohwer Research Station (RRS)	Vegetable Research Station (VRS)
2017 Planting Date	December 11	December 19	December 18
2018 Planting Date	March 19, 2019	DNP[a]	November 30
2019 Planting Date	October 18	October 24	October 18
2019 Sampling Date	May 23	NS[b]	May 14
2020 Sampling Date	May 21	May 1	April 30

a- Did not plant- DNP

b- No sampling- NS

Table 3-3. Abbreviated analysis of variance for the parameters recorded in this trial.

	NDF	DDF	F Ratio	P-Value
Infiltration				
Winter Treatment	7	27.07	2.08	0.0809
Aboveground Biomass				
Winter Treatment	7	101.2	8.99	<.0001
Aboveground N Uptake				
Winter Treatment	7	89.98	10.16	<.0001
Aboveground P Uptake				
Winter Treatment	7	90.04	9.80	<.0001
Aboveground K Uptake				
Winter Treatment	7	90.15	13.57	<.0001
Soil pH				
Winter Treatment	7	21	2.67	0.0384
Soil Organic Matter				
Winter Treatment	7	34.27	1.20	0.3274
Soil Health Calculation				
Winter Treatment	7	33.14	1.06	0.4115

Table 3-4. Mean values for aboveground biomass, aboveground nitrogen (N), phosphorus (P) and potassium (K) uptake, change in soil pH, change in soil health calculation (SHC), change in soil organic matter (SOM) concentration, and water infiltration as influenced by winter cropping systems treatment.

Treatment	Biomass		N Uptake		P Uptake		K Uptake		Soil pH		SHC	SOM	Infiltration
	----------------------------------kg ha^{-1}--------------------------------								ΔpH		ΔSHC	ΔSOM	mm min^{-1}
Austrian Winter Pea	1994.22	ab[a]	42.44	a	5.25	ab	23.29	c	.4	a	2.60	.28	1.43
Barley	1595.36	b	16.39	de	4.99	ab	21.65	c	.4	a	3.81	.36	0.98
Black-seeded Oat	2004.23	ab	17.99	cd	5.31	ab	32.52	ab	.2	b	2.25	.49	1.94
Blue Lupin	1075.78	c	14.94	de	2.32	c	12.00	d	.5	a	1.81	.29	0.56
Cereal Rye	1754.36	ab	16.43	de	4.42	b	19.70	c	.4	a	3.22	.41	2.52
Blend 1	1987.57	ab	23.34	bc	5.57	ab	25.54	bc	.4	a	2.39	.48	1.09
Blend 2	2300.07	a	30.29	ab	6.46	a	36.07	a	.4	a	1.79	.39	0.91
Fallow	740.14	d	12.16	e	2.04	c	9.10	d	.3	ab	3.36	.31	1.15

[a] Means followed by the same letter within a column are not significantly different using α=0.05.

Table 3-5. Variance components for aboveground biomass, aboveground nitrogen (N), phosphorus (P), and potassium (K) uptake, soil pH, soil health calculation (SHC), and soil organic matter (SOM)

Aboveground Biomass

Effect	Estimate	Percent of Total
Site year	0.4485	75.51
Block (Site year)	0	0
Residual	0.1455	24.49
Total	0.594	100

Aboveground N

Effect	Estimate	Percent of Total
Site year	0.2331	55.72
Block (Site year)	0.009821	2.35
Residual	0.1754	41.93
Total	0.418321	100

Aboveground P

Effect	Estimate	Percent of Total
Site year	0.3172	66.30
Block (Site year)	0.005798	1.21
Residual	0.1554	32.48
Total	0.418321	100

Aboveground K

Effect	Estimate	Percent of Total
Site year	0.2924	63.23
Block (Site year)	0.004351	0.94
Residual	0.1657	35.83
Total	0.462451	100

Soil pH

Effect	Estimate	Percent of Total
Site year	0	0
Block (Site year)	0.01243	15.82
Residual	0.06615	84.18
Total	0.07858	100

SHC

Effect	Estimate	Percent of Total
Site year	0	0
Block (Site year)	0.05230	13.62
Residual	0.3318	86.38
Total	0.3841	100

Chapter Four: Summary and Conclusions

The primary goal of this research was to determine if cover crops were a viable alternative to the traditional Arkansas winter practices when implemented into a soybean rotation. A study was designed to observe the effect winter cover crops have on the following soybean crop, evaluate partial returns of each cropping system, and determine the effect that residue could have on soybean establishment. Results of this study showed that there was no effect on soybean establishment following winter cover crops compared to a winter fallow, even when large levels of biomass were produced. However, cover crops did have a positive influence on soybean yield. Although not significantly greater than all cover crop treatments, Blend 2 (Austrian winter pea and black-seeded oat) resulted in numerically greater yields than soybean following other cover crop treatments. The double-crop soybean system resulted in yields lower than cover crop treatments and numerically lower than soybean following winter fallow. Soybean yield following winter fallow was numerically lower than each cover crop treatment. The partial budget analysis concluded each cover crop treatment, excluding blue lupin, returned more than a winter fallow management program, and although not significantly different, double-crop soybean returned more than cover crop treatments due to the added revenue of the wheat crop.

When evaluating a variety of cover crops predicted to be suitable for an Arkansas climate, it was observed that cover crops could produce up to four times as much biomass compared to the winter fallow treatments, with Blend 2 producing the greatest biomass. The biomass production directly affected the aboveground uptake of N, P, and K. Treatments that accumulated large amounts of biomass took up the most nutrients and contributed to numerically greater SOM. Although amounts of biomass affected nutrients, there was no clear effect on SOM and water infiltration. This was expected due to the moisture condition of the soils that were tested. The cracks present likely played a large role in the water infiltration readings. Each cover crop treatment, as well as fallow, resulted in a soil health score above 7, which indicates a healthy soil despite no differences among treatments following three continuous years of winter cover crop and no-tillage treatments.

While the double-crop system resulted in similar partial returns as soybean following cover crop treatments, cover crops have shown that they can provide both short- and long-term benefits that winter wheat is unable to provide. Results of this study indicated that each cover crop and cover crop blend showed promise for implementation in an Arkansas cropping system as an alternative for both double-crop soybean and winter fallow, except for blue lupin which proved to be unsuitable for Arkansas' climate. Due to winters being too harsh, blue lupin experienced winter-kill every year, resulting in low biomass accumulations and decreased benefits. To maximize benefits from cover crops, it is crucial to choose and plant the appropriate species or blend on time, use proper termination techniques to ensure the success of the subsequent soybean crop, and continue a no-tillage system.