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| Project Number:  | 1820-172-0132-A |
| Project Title:  | Economic and environmental impact of multi-use cover crop species in Tennessee no-till soybean/corn rotations |
| Organization:  | The University of Tennessee |
| Principal Investigator Name: | Virginia R. Sykes |
| Project Status - What key activities were undertaken and what were the key accomplishments during the life of this project? Please use this field to clearly and concisely report on project progress. The information included should reflect quantifiable results (expand upon the KPIs) that can be used to evaluate and measure project success. Technical reports, no longer than 4 pages, may be included in this section.  |
| **Introduction**Cover crop species can offer many ecological benefits when incorporated into soybean production systems. However, the magnitude of these returns is highly dependent on regional adaptation and adaptation to rotation systems which may vary in timing of cover crop establishment and termination. An additional concern in introducing cover cropping to an established row crop system is achieving balance of ecological benefits with economic returns. One way in which cover crops may provide additional, and more immediate, economic returns is through dual-use as both a cover and a forage crop. The objectives of this study were to 1.) determine cover crop species suitability to Tennessee under two rotation systems which vary in establishment/termination timing, and 2.) assess economic and ecological advantages or disadvantages to those cover crop species when used in a conventional cover crop system compared with a dual-use cover crop/forage system. To address these objectives, 18 different cover crop treatments were examined at three locations in Tennessee (Knoxville, Spring Hill, and Milan) under two cover crop establishment/termination timings (long season - following corn/preceding soybeans and short season - following soybean/preceding corn) and two management practices (conventional cover, dual-use cover/forage). **Methods**Treatments were arranged in randomized complete block design with three replications and planted at three AgResearch and Education Center in Tennessee in the fall of 2017: Knoxville (ETREC), Spring Hill (MTREC), and Milan (RECM). The dual-use management practice treatment was not included at the Milan location since forage production is less prevalent in that region. Legumes were inoculated with a species appropriate rhizobium inoculant at the recommended rate prior to planting. All species were planted at either 1 - 2 in. or 0.25 - 0.5 in. depth based on recommendations in the UT extension publication “Forage and Field Crop Seeding Guide for Tennessee”. Long season plots were planted 25-26 Sept. 2018 and short season plots were planted 25-27 Oct. 2017. Collection of plant height and percent cover data began on all plots approximately one month after establishment and continued on a monthly basis. Plant height was measured in cm using a height stick. Percent cover was measured using Canopeo digital image analysis software (Oklahoma State University). Estimated biomass was evaluated on forage plots monthly and on non-forage plots immediately prior to termination by hand-clipping all biomass from a randomly selected 1 ft2 sample. Biomass was divided into crop species and weed material and each weighed separately to assess botanical composition. Samples were dried at 104 °F for 72 hours and reweighed to calculate total dry matter yield. Cover crop forage plots were harvested late March to early April (short-season) and mid to late April (long-season). Harvest equipment varied by location but all plots were cut at a height of 2 inches. Harvested material was weighed using a scale attached to a tarp suspended from a tripod. A sample of approximately 2 lbs was collected from the harvested biomass and dried in an oven at 104°F until dry weights remained stable. From these data, percent moisture was calculated and used, in combination with plot weights, to determine total dry matter yield per acre. Dried samples were ground using a Wiley mill with a to 1-mm mesh. Ground samples were then analyzed for nutritional composition using near infrared spectroscopy using calibration models developed by the NIRS Consortium (Hillsboro, WI). Plots were terminated approximately one week after forage harvest using a non-selective herbicide and cash crops were planted approximately one week after termination (30 April – 7 May 2018). Corn at the ETREC location had to be replanted three weeks after initial planting due to severe stand loss from birds. A non-selective herbicide and a pre-emergent herbicide were applied at planting. Total percent weed coverage was rated visually at two weeks post planting at MTREC and ETREC locations. Because weeds were approaching heights that would limit effective herbicide control, an application of glufosinate was applied at one month post planting and additional weed measurement values were not included. Soil samples were collected at a depth interval of 0-6 inches two months after cover crop harvest and analyzed for the following: organic acid H3A-2 (2g*/*L lithium citrate + 0.6g*/*L citric acid + 0.4g*/*L malic acid + 0.4g*/*L oxalic acid) extractable phosphorus, potassium, calcium, magnesium, sulfur, manganese, zinc, boron, iron, sodium, aluminum, phosphate (PO4-P), available nitrogen (NO3--N + NH4+-N), water extractable organic carbon (WEOC), water extractable nitrogen (WEON), total nitrogen, and 1-day soil respiration (Solvita). Based on the above analyses, a soil health score (1-day CO2-C/10 + WEOC/100 + WEON/10) was calculated for each individual plot. Available nitrogen, phosphorus, and potassium (lb/acre) for crops were calculated. Some important soil nutrient ratios [Ca/Mg, (Ca+Mg)/Al] were also calculated. In addition, these soil samples were also analyzed for the basic chemical properties related to soil health including pH; organic matter, cation exchange capacity (CEC), and percentage of base saturation of cation. Population of earthworms was determined on a plot basis during the mid-growing season of soybean and corn in 2018. Sampling was done using two 30- × 30-cm soil monoliths per plot from which earthworms were sorted by hand. Cash crops were harvested at maturity using an Almaco combine. Grain samples were analyzed using NIR for starch (corn only), oil, and protein.All statistical analyses were performed using a mixed model analysis of variance which was run using the glimmix procedure in SAS (v. 9.4, Cary, NC). In all analyses, location was considered random and all other effects were considered fixed. Species, season, and species by season effects were analyzed using non-forage plots, which were evaluated at all three locations. Harvest effect and all interactions with harvest were evaluated for forage and non-forage plots, which were only at the ETREC and MTREC locations. Means were separated using Fisher’s protected LSD. Significance was determined using a 0.05 level of probability. **Results** *Seasonal Cover Crop Percent Cover* All species tended to exhibit greater percent cover crop cover throughout the growing season when established earlier, however, differences between long and short season performance differed by species and sampling month. Some species did poorly in both long and short season conditions, including arrowleaf clover, berseem clover, sunn hemp, turnip, and common vetch. Maximum percent cover was reached under long season conditions with the cereals and brassicas peaking in Dec. (barley (67%), canola (56%), cereal rye (60%), forage radish (58%), oat (59%), triticale (63%), turnip (43%), wheat(59%)) while the majority of the legumes did not reach maximum percent cover until Apr. (arrowleaf clover (36%), crimson clover (92%), red clover (86%), hairy vetch (88%), woolypod vetch (92%), winter pea (81%)). Exceptions to this were common vetch (51%) and berseem clover (21%) which reached max cover in Dec. Under long season conditions, the well-adapted legumes, including crimson clover, red clover, hairy vetch, woolypod vetch, and winter pea, averaged 57% cover across the growing season compared to the cereals, barley, cereal rye, oat, triticale, and wheat, which averaged only 42%. Under short season conditions, this trend was reversed with cereals maintaining a higher average percent cover (26%) compared with the well-adapted legumes (15%). *Forage Yield*Long season plots tended to have higher forage yield compared with short season plots, but this difference was only significant for crimson clover (+168 tons/ac), red clover (+84 tons/ac), hairy vetch (+117.8 tons/ac), woolypod vetch (+107 tons/ac) and winter pea (+108 tons/ac). The long season crimson clover produced the highest amount of biomass, across location and season,, averaging 188 tons/ac, followed by long season hairy vetch (141 tons/ac), winter pea (131 tons/ac), and woolypod vetch (129 tons/ac). Long season wheat (100 tons/ac) was significantly higher than the no cover control, but did not differ significantly from yields under the short season. All remaining species under either short or long season did not exhibit forage yields that differed significantly from the no cover control. *Forage Quality* Forage protein, Ca, P, Mg, dNDF30, dNDF48, IVTDMD30, and ash differed significantly by species but not by season. As expected, the legumes tended to have higher quality compared to the cereals. In particular, crimson clover, red clover, common vetch, hairy vetch, woolypod vetch, and winter pea had significantly higher protein and IVTDMD30 compared with cereal rye, triticale, barley, wheat, and oat, which did not differ from the no cover control. Compared to the no cover control, cereal rye, oat, triticale, and wheat had significantly lower Mg and Ash and significantly higher dNDF30 and dNDF48. Nearly all species treatments exhibited significantly higher Ca compared with the no cover control, with exception to berseem clover and common vetch. The only forage quality trait to exhibit a significant species by season interaction was ADF. For this trait, values were lower in the long season plots for some of the species, including barley, cereal rye, oat, triticale, wheat, crimson clover, red clover, common vetch, and winter pea, but did not differ between long and short season plots for the remaining species. *Weed Suppression*No significant difference in percent weed cover at 2 weeks post planting was observed by species, season, or harvest.*Soil Health*Seasons and species differed significantly for several of the measured soil attributes. Values were higher in the long season plots for water extractable carbon, C/N ratio, and average soil moisture, which was expected due to the higher amounts of biomass residue on these plots. In short season plots, water extractable nitrogen, available nitrate, organic matter, and estimated nitrogen release were higher. This was unexpected as we hypothesized that the higher residue amounts would result in greater nutrient availability to subsequent cash crops. This may have been caused by a short-term reduction due binding of these elements during decomposition of the cover crop residue. A second year of data will be necessary to further elaborate on these results. Several soil measurements also differed by species. Compared with no cover control, cereal rye reduced water available nitrogen, cereal rye and oat resulted in higher C/N ratios, and triticale exhibited a small, but significant, increase in pH. Soil measurements did not differ between forage and non-forage plots for the short season cover crops, however, harvesting long-season cover crops as a forage resulted in significantly higher water extractable N, available phosphate, and available ammonium and significantly lower C/N ratio. While lower C/N ratio was expected, due to the removal of biomass, an increase in extractable N and available phosphate was not expected. Again, this may have been a short-term reduction due to binding of these elements in the decomposition process, but will need to be confirmed through a second year of data. Our one year data suggest that harvesting cover crops as forage may add an economic benefit without any significant reduction in the ecological benefits this management practice offers.*Cash Crop Yield, and Quality*Cash crop yield and most quality traits were not affected by species, season, or harvest. The exception to this is protein in both corn and soybeans. Corn exhibited a significant species effect, with a reduction in corn protein when following a barley (- 0.24%) or cereal rye (- 0.24%) cover crop compared with the no cover control. In soybean, the differences in species also differed significantly by harvest treatment. A small, but significant, increase in soybean protein was observed following the non-forage red clover (+0.62%) and wheat plots (+0.72%) compared with the respective forage plots. The remaining species showed no significant difference between forage and non-forage treatments. Wheat harvested as a forage was also the only species to exhibit a reduction in protein of the succeeding soybean crop compared with the no cover control (-0.55%). *Conclusion*Results from this study provide important information to help producers select regionally adapted cover crop species that will provide maximum ecological benefits under their corn/soy or soy/corn rotation systems in the Mid-South. In addition, these results suggest that dual-use cover cropping systems may provide an economic advantage through the production of high quality forage without significantly reducing the important ecological benefits that cover cropping systems offer. Because year to year environmental variation, particularly difference in temperature extremes, can have a significant impact on species adaptation, a second year of data collection is essential to confirm results from our first year studies prior to making firm recommendations to US soybean farmers.First year data has been presented to approximately 166 extension agents and producers through the Milan Cover Crop Field Day (27 March 2018) and Milan No-Till Field Day (26 July 2018). This information will be further disseminated through upcoming presentations at the American Society of Agronomy in Baltimore, MD (5 Nov. 2018) and at a UT Extension in-service training on 27 Nov. 2018. A popular press blog article is also being developed to be published on utcrops.com.  |
| Did this project meet the intended Key Performance Indicators (KPIs)? List each KPI and describe progress made (or not made) toward addressing it, including metrics where appropriate.  |
| The KPIs for this project are listed below. This project was originally planned as a three year project, which included two years of field data collection with presentations of first year results in year 2 and presentations, publications, and development of a web-based cover crop selection tool in year 3. In year 1, progress was made towards the first KPI, with 166 producers/extension agents reached through presentations at the Milan Cover Crop Field Day (27 March 2018) and Milan No-Till Field Day (26 July 2018). We will continue to reach producers in year 2 by sharing year 1 results through presentations at extension in-service training, field days, and producer meetings, as funding is available, and through blog posts on utcrops.com. Metrics for these activities will not be available until the end of year 2. The United Soybean Board did not fund a second year of data collection for this study, therefore development of the web-based cover crop selection tool (KPI 2) will not be possible since the dataset is limited to only a single year and funding is not available for hiring a web developer. We will continue to seek funding to continue this project. * *Over 80% of Tennessee soybean producers will receive regionally appropriate cover crop species performance data through presentations or publications resulting from this project; 15% of producers will implement cover crop species in their production system or change their cover crop system to one that is more economically and ecologically appropriate to their region.*
* *Producers throughout the mid-South and beyond will have access to results through the UTcrops blog. A web based cover crop selection tool for the mid-South will also be made available through the UTcrops site. This blog had 83,163 page views in 2016. This tool and results will help mid-South soybean producers make more economically and ecologically appropriate decisions on cover crop use in their production systems.*
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| Expected Outputs/Deliverables - List each deliverable identified in the project, indicate whether or not it was supplied and if not supplied, please provide an explanation as to why. |
| Listed below are the expected outputs/deliverables that were listed in the proposal for this project. Because this project required a full year to collect all data (from cover crop establishment in Sept. 2017 through soybean harvest in Oct. 2018), all of the outputs/deliverables were intended for year 2 (presentation of first year results) and year 3 (presentation and publication of final results, development of web-based cover crop selection tool). Although not listed in the expected outputs/deliverables, first year results on the cover crop growing season were presented at the Milan Cover Crop Field Day (27 March 2018) and Milan No-Till Field Day (26 July 2018) which reached approximately 166 extension agents and producers. A no-cost extension for travel to present first year data was not approved by the United Soybean Board, however, these data are also scheduled to be presented in an oral presentation at the American Society of Agronomy annual meeting in Baltimore, MD on 5 Nov. 2018, thanks to funding support from UT AgResearch, and at a UT Extension in-service training on 27 Nov. 2018. A blog post for utcrops.com relaying first year results is also still planned for delivery in year 2. Because year to year environmental variation, particularly difference in temperature extremes, can have a significant impact on species adaptation**,** it will not be possible to put together Extension or Research publications or develop a mobile friendly, web-based cover crop selection tool with only a single year of data due to discontinued funding from the United Soybean Board. Extension Publications (year 3)* + Cover crop species fact sheets
	+ Fact-sheet on economics of dual use cover crop species for Tennessee
	+ Blog articles on UT website (year 2, year 3)

Presentations (year 2, year 3)* + Milan Cover Crop Field Day
	+ Milan No-Till Field Day
	+ Extension in-service trainings (approx.. 2 per year)
	+ Grain Conference meeting (3 per year)

Other applications (year 3)* + Mobile friendly, web-based cover crop selection tool

ResearchPublications (year 3) * + Research publications targeted towards Agronomy Journal

Presentation (year 2, year 3) * + American Society of Agronomy annual meeting
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| Describe any unforeseen events or circumstances that may have affected project timeline, costs, or deliverables (if applicable.) |
| The timeline proposed for year 1 is listed below and was executed as planned. No unforeseen events or circumstances affected the project timeline, costs, or deliverables during this period. Because this project was planned for three years total, and funding was only made available for the first year, overall project deliverables which rely on two years of field data collection, including Extension and Research publications and development of a web-based cover crop selection tool, will not be possible without continued funding support. Year 1 (Oct. 1, 2017 – Sept. 30, 2018)* Recruit qualified students and technical staff
* Conduct the field trial and collect data for year 1
* Present first year cover crop performance at:
	+ UT Cover Crop Field Day (Mar. 2018)
	+ Milan No-Till Field Day (July 2018)

Year 2 (Oct. 1, 2018 – Sept. 30, 2019)* Conduct the field trial and collect data for year 2
* Analyze year 1 data and write annual report for year 1 (Oct. – Dec. 2018)
* Present first year cover crop/cash crop results at
	+ extension winter meetings (Nov. 2018 – Feb. 2019)
	+ UT Cover Crop Field Day (Mar. 2019)

Year 3 (Oct. 1, 2019 – Sept. 30, 2020)* Analyze year 2 data and write final report (Oct. – Dec. 2019)
* Develop research and extension publications (Oct. – Dec. 2019)
* Present final results at
	+ professional conference (Oct. – Nov. 2019)
	+ winter extension meetings (Oct. – Dec. 2019)
	+ UT Cover Crop Field Day (Mar. 2020)
	+ Milan No-Till Field Day (July 2020)
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| What, if any, follow-up steps are required to capture benefits for all US soybean farmers?Describe in a few sentences how the results of this project will be or should be used. |
| The first year results from this project indicate clear differences in regional adaptation by species, differences in species adaption to corn/soy rotations compared with soy/corn rotations, and potential economic benefit without negative ecological impact by using a dual-use forage/cover cropping system. These results will help mid-South soybean producers identify cover crop species and management systems that will maximize both economic and ecological benefits in their production system. Because year to year environmental variation, particularly difference in temperature extremes, can have a significant impact on species adaptation, a second year of data collection is essential to confirm results from our first year studies prior to making firm recommendations to US soybean farmers. Because the results of this project can have a significant economic and ecological impact on US soybean production systems, we will continue to seek funding to support a second year of data collection for this project.  |
| **List any relevant performance metrics not captured in KPI’s.** |
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