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| Project Number:  | 1820-172-0132-B |
| Project Title:  | Long-Term Effects of Cover Crops and Crop Rotations on Soil Health and Water Availability |
| Organization:  | University of Tennessee |
| Principal Investigator Name: | Frank Yin |
| 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.  |
| The following activities were undertaken during the first year of this project to fulfill the objectives in the proposal.

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**Materials and Methods****Field trial** An already existing long-term field experiment of cover crops and crop rotations at The University of Tennessee Research and Education Center at Milan was used for this project in order to reduce the costs on this project. This experiment was initiated in 2002, and so far has been continually conducted on the same field for 16 years. The combinations of four winter-season cover crop treatments of no cover crop (fallow), hairy vetch, chicken litter, and wheat interacted with three crop rotation treatments of continuous soybean, corn-soybean, and soybean-cotton in a split-plot design with three replications were used in this project. For 2018, corn was the crop grown in corn-soybean rotation, and soybean was the crop grown in soybean-cotton rotation. Corn and soybean were planted in the selected plots on May 9, 2018. **Data collection***Soil health tests* Soil samples were collected at the depth intervals of 0-6, 6-12, 12-24, and 24-36 inches with 10 cores/sample from each plot for the analyses of soil health before corn and soybean planting on April 9-11, 2018. The following soil health analyses were conducted on the above soil samples: 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 (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), copper (Cu), zinc (Zn), boron (B), iron (Fe), sodium (Na), aluminum (Al), phosphate (PO4-P), and available nitrogen (N) (NO3—N, NH4+-N); water extractable organic carbon (WEOC); water extractable nitrogen (WEON); and 1-day soil respiration (Solvita). A soil health score was calculated for each plot with the following equation: 1-day CO2-C/10 + WEOC/100 + WEON/10. Available N, P, and K (lb/acre) for crops were calculated. Some important soil nutrient ratios [Ca:Mg, (Ca+Mg):Al] were also calculated. *Soil water availability*Soil water availability is another key indicator of soil health. Soil samples were collected in the top 6 inches with three samples from each plot for the determination of soil moisture content during the late growing season on August 13, 2018. *Soil chemical properties and nutrient cycling*The soil samples collected for the above soil health tests were also used for the analyses of some basic chemical properties which are highly related to soil health in 2018. The soil chemical characterizations consisted of soil pH, organic matter, cation exchange capacity (CEC), and percentage of base saturation of cation with Mehlich 3 as the extractant. *Soil biological properties*Population of earthworms is another important measurement of soil health. Population of earthworms was determined on a plot basis during the growing season. Sampling was done using 30- × 30 × 15-cm soil monoliths from which earthworms were sorted by hand. Two monoliths were taken from each corn plot on June 14, 2018 and from each soybean plot on June 25, 2018. *Crop nutrition and yields*A composite leaf sample was collected at the V6, V10, and R3 growth stages of soybean and V6, V10, and R1 growth stages of corn in 2018; the specific sampling dates were June 14, June 25, July 16 for soybean and June 6, June 14, and July 5 for corn. A composite whole plant sample was taken at the physiological maturity stage of soybean on September 18 and of corn on September 14 in 2018. Nutrient (N, P, K, Ca, Mg, S, and selected micronutrients) concentrations in these leaf and whole plant samples were determined. Grain yields of soybean and corn were determined at maturity from the two center rows in each plot on October 17 and September 18, 2018, respectively. A composite grain sample was taken from each plot at soybean and corn harvest. Nutrient (N, P, K, Ca, Mg, S, and selected micronutrients) concentrations in these grain samples were determined. The removal of these nutrients due to crop harvest was calculated. **Data analysis**Statistical analyses were conducted on the measurements of 2018 with appropriate methods and software.**Results and Discussion****Long-term effects of cover crops on earthworm, moisture, respiration, water extractable C and N, and health score of soil**Our soil health results of 2018 showed that there were significant differences in water extractable soil N in 0-6 inches (Table 1), with chicken litter resulting in higher water extractable soil N content than fallow and wheat. However, no significant difference in water extractable soil N was observed among the four cover crop treatments in the deeper layers (data not shown). There were no significant differences in earthworm, moisture, respiration, water extractable organic C, C/N ratio, or health score of soil among fallow, hairy vetch, chicken litter, and wheat regardless of soil depth (data in the 0-6 inch layer are presented in Table 1, but those of deeper layers are not shown). Meanwhile, soil pH, organic matter, or CEC did not differ among the four cover crops in any soil depth (data not shown). Table 1. Long-term effects of cover crops on earthworm, moisture, respiration, water extractable C and N, and health score of soil.

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| --- | --- | --- | --- | --- | --- |
| Soil depth (in.) | Cover crop | Earthworm | Soil moisture | Soil respiration | Water extractable macronutrients |
|  |  |  |  |  | C  | N | C/N | Soil health score |
|  |  | counts | % | mg/kg | mg/kg | mg/kg |  |  |
| 0-6 | Fallow | 4.9a | 29.7a | 80.2a | 157.7a | 9.5b | 17.6a | 10.4a |
|  | Hairy vetch | 2.0a | 28.7a | 82.0a | 166.6a | 11.9ab | 15.1a | 10.8a |
|  | Chicken litter | 3.4a | 30.0a | 102.0a | 182.9a | 15.4a | 13.9a | 13.3a |
|  | Wheat | 1.7a | 28.0a | 94.0a | 169.5a | 11.6b | 15.9a | 12.0a |
|  | Significance | ns | ns | ns | ns | \* | ns | ns |

\* Means in a column followed by different letters are significantly different with Fisher’s protected least significant difference (LSD) at 0.05 probability level.Significance indicates statistical significance for the F test. \*, significant at 0.05 probability level; ns, not significant at 0.05 probability level.**Long-term effects of cover crops on H3A extracted macronutrients in soil**There were significant differences in soil nitrate-N in 0-6 niches, P and K in 0-6 and 6-12 depths, Ca in 0-6 inches, Mg in 0-6, 6-12, and 12-24 inches, and S in 24-36 inches with H3A as the extractant among the four cover crop treatments (Table 2). Specifically, hairy vetch, chicken litter, and wheat resulted in higher nitrate-N content than fallow in 0-6 inches (Table 2). Significant higher P and K levels were observed under chicken litter than fallow, hairy vetch, and wheat in the 0-6 and 6-12 inch depths. Chicken litter caused significant higher Ca content than fallow, hairy vetch, and wheat in 0-6 inches. Magnesium content was significant higher with chicken litter than fallow, hairy vetch, and wheat in 0-6 inches and hairy vetch and wheat in 6-12 inches. Sulfur content was significantly higher under chicken litter than the other cover crop treatments in 24-36 inches. Because chicken litter contains N, P, K, Ca, Mg, and S, the contents of these nutrients were higher in some soil depths under chicken litter than the other cover crop treatments.  Table 2. Long-term effects of cover crops on H3A extracted macronutrients in soil.

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| --- | --- | --- |
| Soil depth (in.) | Cover crop | H3A extracted macronutrients |
|  |  | NO3--N | NH4+-N | P | K | Ca | Mg | S |
|  |  | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| 0-6 | Fallow | 0.63b | 1.04a | 23.7b | 45.8b | 133.9b | 38.7b | 13.0a |
|  | Hairy vetch | 1.10a | 1.23a | 25.2b | 35.2b | 125.1b | 32.4b | 10.3a |
|  | Chicken litter | 1.21a | 1.06a | 118.6a | 107.2a | 160.8a | 55.4a | 14.9a |
|  | Wheat | 1.15a | 1.29a | 35.0b | 55.3b | 141.6b | 36.1b | 11.3a |
|  | Significance | \* | ns | \*\*\* | \*\* | \*\*\* | \*\*\* | ns |
|  |  |  |  |  |  |  |  |  |
| 6-12 | Fallow | 1.12a | 1.20a | 13.2b | 26.6b | 136.2a | 36.6ab | 19.3ab |
|  | Hairy vetch | 1.34a | 1.24a | 16.4b | 28.9b | 135.2a | 28.4c | 14.9b |
|  | Chicken litter | 1.00a | 1.28a | 38.4a | 57.8a | 122.7a | 39.2a | 27.0a |
|  | Wheat | 0.99a | 1.37a | 16.8b | 30.4b | 131.8a | 33.2bc | 15.8b |
|  | Significance | ns | ns | \*\* | \*\* | ns | \*\* | \* |
|  |  |  |  |  |  |  |  |  |
| 12-24 | Fallow | 1.47a | 1.07a | 10.7a | 20.1a | 119.8a | 43.4a | 36.9a |
|  | Hairy vetch | 1.94a | 2.76a | 10.9a | 28.8a | 115.4a | 32.1b | 26.1a |
|  | Chicken litter | 1.08a | 1.04a | 14.2a | 30.0a | 114.8a | 40.0ab | 43.7a |
|  | Wheat | 1.82a | 1.24a | 9.4a | 19.1a | 114.1a | 30.7b | 23.9a |
|  | Significance | ns | ns | ns | ns | ns | \* | ns |
|  |  |  |  |  |  |  |  |  |
| 24-36 | Fallow | 1.23a | 1.16a | 10.8a | 22.8a | 95.8a | 47.1a | 27.0b |
|  | Hairy vetch | 2.13a | 1.86a | 12.0a | 44.7a | 90.6a | 45.1a | 24.6b |
|  | Chicken litter | 1.29a | 1.10a | 11.9a | 23.3a | 109.4a | 44.7a | 45.8a |
|  | Wheat | 1.51a | 1.10a | 9.6a | 25.4a | 86.9a | 37.8a | 23.8b |
|  | Significance | ns | ns | ns | ns | ns | ns | \* |

\* Means within a soil depth in a column followed by different letters are significantly different with Fisher’s protected LSD at 0.05 probability level.Significance indicates statistical significance for the F test. \*, significant at 0.05 probability level; \*\*, significant at 0.01 probability level; \*\*\*, significant at 0.001 probability level; ns, not significant at 0.05 probability level.**Long-term effects of cover crops on H3A extracted micronutrients in soil**Significant effects of cover crops were observed on Mn in 0-6, 6-12, and 12-18 inches, Cu and Zn in 0-6 and 6-12 depths, and Fe in 24-36 inches with H3A as the extractant (Table 3). Hairy vetch resulted in higher Mn content than fallow and chicken litter in 0-6, 6-12, and 12-18 inches (Table 3). Chicken litter caused higher Cu and Zn levels than fallow, hairy vetch, and wheat in 0-6 and 6-12 depths. Soil Fe content was higher with hairy vetch than fallow, chicken litter, and wheat in 24-36 niches. Table 3. Long-term effects of cover crops on H3A extracted micronutrients in soil.

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| --- | --- | --- |
| Soil depth (in.) | Cover crop | H3A extracted micronutrients |
|  |  | Mn | Cu | Zn | B | Fe |
|  |  | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| 0-6 | Fallow | 17.8c | 0.54b | 0.66b | 0.38a | 135.8a |
|  | Hairy vetch | 43.3a | 0.60b | 0.75b | 0.43a | 159.2a |
|  | Chicken litter | 25.9bc | 1.65a | 3.50a | 0.51a | 148.3a |
|  | Wheat | 33.7ab | 0.66b | 0.91b | 0.55a | 200.1a |
|  | Significance | \*\*\* | \*\*\* | \*\*\* | ns | ns |
|  |  |  |  |  |  |  |
| 6-12 | Fallow | 12.1c | 0.45c | 0.43b | 0.31a | 107.9a |
|  | Hairy vetch | 44.8a | 0.59b | 0.56b | 0.37a | 151.7a |
|  | Chicken litter | 19.6bc | 0.86a | 1.13a | 0.39a | 105.7a |
|  | Wheat | 35.0ab | 0.65b | 0.66b | 0.35a | 147.6a |
|  | Significance | \*\* | \*\*\* | \* | ns | ns |
|  |  |  |  |  |  |  |
| 12-24 | Fallow | 6.0b | 0.55a | 0.41a | 0.34a | 107.2a |
|  | Hairy vetch | 14.9a | 0.62a | 0.60a | 0.38a | 150.6a |
|  | Chicken litter | 7.7b | 0.58a | 0.44a | 0.31a | 98.9a |
|  | Wheat | 10.2ab | 0.61a | 0.41a | 0.28a | 110.6a |
|  | Significance | \* | ns | ns | ns | ns |
|  |  |  |  |  |  |  |
| 24-36 | Fallow | 8.2a | 0.65a | 0.42a | 0.33a | 121.9b |
|  | Hairy vetch | 8.7a | 0.73a | 0.92a | 0.58a | 264.0a |
|  | Chicken litter | 7.6a | 0.68a | 0.55a | 0.37a | 107.1b |
|  | Wheat | 6.2a | 0.67a | 0.55a | 0.38a | 160.8b |
|  | Significance | ns | ns | ns | ns | \* |

\* Means within a soil depth in a column followed by different letters are significantly different with Fisher’s protected LSD at 0.05 probability level.Significance indicates statistical significance for the F test. \*, significant at 0.05 probability level; \*\*, significant at 0.01 probability level; \*\*\*, significant at 0.001 probability level; ns, not significant at 0.05 probability level.**Long-term effects of crop rotations on soil health parameters**There were no significant differences in population of earthworm, moisture, respiration, water extractable C and N, health score, pH, organic matter, or CEC of soil among continuous soybean, corn-soybean, and soybean-cotton in any soil depth in 2018 (data not shown). Meanwhile, H3A extracted macronutrients or micronutrients generally did not differ among the three crop rotation treatments regardless of soil depth (data not shown). There was roughly no significant interactive effect between crop rotations and cover crops on the above measurements in any soil depth (data not shown).**Summary** Our 2018 results indicate that annual application of chicken litter as an N source since 2002 has significantly increased available N, P, K, Ca, Mg, Mn, Cu, and Zn contents in top 0-6 inches of soil. These increases will be beneficial for improving soil supply of these nutrients to the crop, but it will also increase the risks of losing these nutrients particularly P to both surface waters and underground waters. Soybean in rotation with corn or cotton results in similar soil health status as continuous soybean from a long-term perspective, which suggests growing soybean continuously year by year has no adverse effect on soil health relative to the commonly used corn-soybean and soybean-cotton rotations.  |
| 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.  |
| This project was planned for two years in the proposal, but the United Soybean Board decided to fund it for Year 1 only. During the first year, we completed everything based on the proposal in a timely manner, such as selecting an appropriate field trial for this project, implementing all the treatments, taking samples and measurements, and analyzing the soil and plant samples. All the data have so far been statistically analyzed, and the main results are presented in the previous section of this report. * 80% of soybean producers in TN and some other farmers in other states will receive the results of this project through attending the presentations of project results; that may result in improved long-term sustainability of the soil and thereby maintain farm profitability. The understanding of the long term benefits of cover crops in different crop rotations may allow growers to more efficiently choose cover crop options for their farm.

The progress has been made because we have got the results of Year 1. Since the crops were just harvested by mid-October 2018, there was no time for us to give Extension presentations. However, we will present the one-year results of this project to farmers, private consultants, county extension agents, governmental representatives, and industry agronomists at extension meetings and trainings during the coming year. * Over 1000 of soybean farmers will receive the relevant Extension article in hard copy or electronically.

The progress has been made because we have got the results of Year 1. Since the crops were just harvested by mid-October 2018, there was no time for us to write the Extension article. However, we will write an extension article and publish it on UTcrops blog during the coming year. * 15% of soybean farmers in Tennessee will begin to use the management practices generated by this project in their soybean production immediately after the completion of this project.

Through our Extension activities such as presentations and publication, some producers will adopt appropriate cover crop species and crop rotations to make their production systems to be more profitable and sustainable. The progress has been made because we have got the results of Year 1. Since the crops were just harvested by mid-October 2018, there was no time for us to give Extension presentations or write an Extension article so as to encourage farmers to use the management practices generated by this project. However, we will encourage farmers to adopt the management practices generated by this project on their farms through extension presentations and publication during the coming year.  |
| 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. |
| The deliverables of this project are listed below: * The trial site of the long-term cover crop and crop rotation experiment at The University of Tennessee Research and Education Center at Milan;

This deliverable was supplied during Year 1.* Reliable and quantitative data on the long-term impacts of cover crops and crop rotations and their interactions onsoil health and their relationships with soil water availability, nutrient cycling, and soybean productivity;

This deliverable was supplied during Year 1.* Site visits, field days, publications, and presentations at Extension meetings about the long-term benefits of cover crops and crop rotations onsoil health, soil water availability, nutrient cycling, and soybean productivity;

Site visits were supplied in Year 1. However, field days, publications, and presentations at Extension meetings were planned to be accomplished in Year 2. As mentioned above, this project was planned for two years in the proposal, but the United Soybean Board decided to fund it for Year 1 only. Since we only have one year of data, which may not be enough for writing a publication. * Attendance and participation of producers in related field days, Extension meetings, and workshops;

Since this deliverable was planned in Year 2, it was so far not supplied.* Inclusion of guidelines for cover crops and crop rotations in soybean production manual.

Since this deliverable was planned in Year 2, it was so far not supplied. For agricultural field research, at least two years of data are required to make reliable recommendations to farmers. |
| Describe any unforeseen events or circumstances that may have affected project timeline, costs, or deliverables (if applicable.) |
| This project was planned for two years in the proposal, but the United Soybean Board decided to fund it for Year 1 only. During this one–year period, we completed everything that we proposed in the proposal on time. Since some of the key performance indicators and expected outputs/deliverables were planned to be accomplished in Year 2 in the proposal, the progresses have been made in Year 1, but they have so far not been fully accomplished. Some of them will even not be able to be fully accomplished since we only have one year of data. For agricultural field research, at least two years of data are required to make reliable recommendations to farmers.  |
| 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. |
| We will present the results of this project to farmers, private consultants, and county extension agents, etc. at extension meetings and trainings during the coming year. We believe that some producers will adopt appropriate cover crop species and crop rotations on their farms according to the findings of this project to make their production systems more profitable and sustainable. We will also write an extension article and publish it on UTcrops blog in the coming year.  |
| **List any relevant performance metrics not captured in KPI’s.** |
| None. |