Impacts of cover cropping system on soybean grain yield, soil health, forage production, and animal performance

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EXECUTIVE SUMMARY

Field trials were established at Newton (CPBES) and Prairie (PRU), MS on fine sandy-loam and heavy clay soils, respectively, and were conducted for two full cropping season rotations (fall 2021 to fall 2022 – year 1; fall 2022 to fall 2023 – year 2). Cropping systems included: conventional soybean (CS); no-till soybean + cereal rye cover crop (CC); and no-till soybean + grazed cereal rye cover crop (GC). Treatments were applied in a randomized complete block design with three replications at each location. Analysis was separated by location. Cover crop, soybean production, animal performance, soil characteristics, and economic analysis were evaluated for each treatment. Soybean grain yield varied by treatment; GC (54.6 bu ac^{-1}) was greater than CS (52.3 bu ac^{-1}) at CPBES. At PRU, CS (68.5 bu ac^{-1}) had greater soybean yield than all other treatments. Cover crop forage mass (FM) was 5,077 lb ac^{-1} at CPBES, compared to 3,094 lb ac^{-1} at PRU, resulting in subsequent cattle revenue of \$593.64 and \$160.29 ac^{-1} for CPBES and PRU, respectively. Soybean revenue was greatest for GC at CPBES (\$691.78 ac^{-1}) and CS at PRU (\$867.89 ac^{-1}). Net returns above production costs were greatest for GC at CPBES (\$811.59 ac^{-1}) and CS at PRU (\$528.58 ac^{-1}). Surface hardness did not impact soybean production at CPBES. Tillage reduced biological and chemical soil characteristics at both locations. Findings suggest grazing cereal rye cover crop has the potential to increase net returns in a no-till soybean system on coarse textured soils; but reduces soybean grain yield on heavy, poorly drained sites.

Core Ideas:

1. No-till soybeans + grazed cereal rye produced the greatest net revenue at Newton.
2. Conventional soybean produced the greatest net revenue at Prairie.
3. Cereal rye cover crop reduced soybean yield at Prairie.
4. Cover crop production impacts subsequent animal performance.
5. Surface hardness (compaction) was not a contributing factor to decreased soybean yield at Newton.
6. Conventional tillage reduced OM and active C at both locations.
7. Conventional tillage resulted in lower total C, total N, and P at Prairie.

BACKGROUND AND OBJECTIVES

Agriculture is faced with challenges and opportunities that are impacted by a range of societal and ecological concerns about how the world and its people can be sustained. There is a growing awareness that the stability and resiliency of our agricultural landscapes appear to be impaired by enterprise specialization, concentration of operations, and expansion of scale, which can disrupt energy and nutrient cycles beyond natural processes. In Mississippi, opportunities exist to combine crop and livestock enterprises in a manner that imparts major benefits to the environment, while simultaneously generating more revenue for agricultural producers. These integrated crop-livestock systems (ICLS) can potentially increase crop yields, enhance natural resource utilization, exploit natural pest control processes, reduce nutrient concentrations and environmental risk, improve soil health parameters, and provide alternative sources of revenue through livestock marketing.

This project seeks to evaluate the impact of cover cropping and livestock grazing on two distinct soil types to determine the ability for ICLS to be profitable in Mississippi soybean production systems. The objectives of this project are: 1) determine the impact of integrated livestock cover crop systems on soybean growth and grain yield; 2) monitor the change in soil physical, chemical, and biological properties during each phase of production; and 3) assess the economic productivity of each system. Data collection will include soybean grain yield, soil health parameters, cover crop biomass and nutritive value, animal weight gain, and economic comparisons within each system.

ACTIVITY/PROGRESS

Objective 1: Determine the impact of integrated livestock cover crop systems on soybean growth and grain yield.

Field trials were conducted over two full cropping season rotations (soybean + cover crop) beginning in the fall of 2021 (fall 2021 to fall 2022 – year 1; fall 2022 to fall 2023 – year 2) at two locations. Locations included the Coastal Plain Branch Experiment Station (CPBES) in Newton, MS (32°20’05,11”N, 89°05’09.60”W) and the Prairie Research Unit (PRU) in Prairie, MS (33°47’22.52”N, 88°39’40.70”W). Soils at each site were predominantly Boswell fine sandy loam (fine, mixed, active, thermic Vertic Paleudalfs) and a Houston clay (very-fine, smectitic, thermic Oxyaquic Hapluderts) at CPBES and PRU, respectively. The field trial at each location consisted of a randomized complete block design with three replications. Treatments included three cover crop systems: conventional soybean (CS); no-till soybean with cereal rye cover crop (CC); and no-till soybean with a grazed cereal rye cover crop (GC). At CPBES, the experimental area consisted of an 18-ac pasture subdivided into nine (2.0 ± 0.1-ac) paddocks. Prior to this study, the experimental area was used for a no-till soybean/cover crop rotation. At PRU, the experimental area consisted of a 45-ac pasture subdivided into nine (5.0 ± 0.1-ac) paddocks. Prior to this study, the experimental area was established in tall fescue pasture. To prepare paddocks at PRU for this experiment, perennial grasses were chemically controlled in the spring and summer, followed by tillage (disking to approximately 6” depth followed by seed-bed finishing with a section harrow) prior to cover crop establishment in the fall of 2021. No tillage was conducted at CPBES prior to treatment initiation. Soils were maintained at both locations according to recommendations from the Mississippi State University Soil Testing Laboratory. All animals used in this experiment were cared for under the auspices of Mississippi State University, Institutional Animal Care and Use Protocol IACUC-21-420.

Cover Crop Management and Data Collection

Experimental treatments were randomly assigned to each paddock at the onset of the experiment. For CC and GC paddocks, cereal rye was established as a cover crop in the fall of each year (2021 and 2022). At CPBES, seeding was accomplished using a no-till drill with 7.5-in row spacing (Truax FLX-II-99, Truax Co.) at 80-lb ac^{-1}. Once seedlings had reached approximately 4-in in height, all CC and GC paddocks were fertilized with urea (46-0-0) at 50-lb N ac^{-1}. At PRU, cereal rye was broadcast at 100-lb ac^{-1} along with urea at 50-lb N ac^{-1} at planting. At both locations, a subsequent N application of urea of 50-lb N ac^{-1} was applied to GC paddocks following the first grazing event for a total of 100-lb N ac^{-1} yr^{-1}. Cover crop seeding rates and N applications are based on current Mississippi State Soil Testing Laboratory recommendations for cool-season annual forage crops without a legume.

Cover crop data collection consisted of forage mass (FM) and nutritive value analysis (CP – crude protein, and TDN – total digestible nutrients). Nine random subsamples were collected from each GC paddock at the beginning of each grazing event at both locations. All samples were hand-clipped from a 2-ft^2 area to a 3-in stubble height, weighed, placed in a forced-air oven at 140 ^{o}F for approximately 72-hr, and reweighed to determine percentage moisture and to calculate dry matter for FM analysis. Mean cumulative FM was calculated from the sum of dry matter from samples collected by location for each year. Dried samples were then ground (Thomas-Wiley Laboratory Mill, Thomas Scientific) to pass through a 0.3-in sieve and were analyzed using near-infrared reflectance spectroscopy (NIRS; SpectraStar 2600XTR; Ucal Calibration Software v3.0). Nutrient analysis was determined using the 2021 grass hay equation (NIRS Forage and Feed Testing Consortium) in which CP, acid detergent fiber (ADF), neutral detergent fiber (NDF), fat, lignin, ash, and mineral (Ca, K, Mg, and P) concentrations were derived. The TDN calculation was the sum of the digestible fiber (dNDF), CP, fat, and carbohydrate components.

Cattle Management and Data Collection

Beef heifers were used at both locations to graze GC paddocks for both years of the experiment. At CPBES, predominantly Angus crossbred yearling heifers were used with initial body weights of 671 ± 100 lb hd^{-1} and 619 ± 107 lb hd^{-1} for year 1 and 2, respectively. At PRU, predominantly Charolais crossbred weaned heifers were used with initial body weights of 505 ± 57 lb hd^{-1} and 620 ± 61 lb hd^{-1} for year 1 and 2, respectively. Prior to the initiation of grazing for each year, heifers were placed on stockpiled cereal rye pasture 12-d for rumen microbial population adjustment. After this pre-trial period, animals were evenly stratified by weight and placed on GC paddocks at a recommended target stocking rate (1,500 lb ac^{-1}) for cool-season annual pasture. This procedure aided in forage management and reduced the challenges with determining the optimum number of animals to place on each individual paddock.

Grazing was initiated once cereal rye sward heights reached approximately 10-in. Heifers continuously grazed each paddock until forage reached approximately 4-in in height and were then removed and placed back on stockpiled cereal rye pasture. Grazed paddocks were allowed to rest until restocking levels were achieved. During each grazing season, animals had *ad libitum* access to mineral and fresh water. All heifers at both locations were weighed unshrunk at the beginning and end of each grazing period. Data collection included animal days (AD), average daily gain (ADG), and total gain per acre (GAIN). Animal days were calculated by the sum of the number of days animals remained on each paddock divided by the total size of the paddock and are reported as d ac^{-1}. Average daily gain was calculated by dividing total animal weight gain by the number of days grazing for each animal. Total gain per acre was calculated by dividing total weight gain of all animals in each paddock by the actual size of the paddock (Rushing et al., 2022).

Crop Management and Data Collection

Soybean management varied across treatments and locations. Prior to planting, all treatments at both locations received a burndown application of glyphosate at 1 qt ac^{-1} (4.0 lb a.i. gal^{-1}) to desiccate cereal rye cover crop in CC and GC paddocks, and annual cool-season weeds in CS paddocks. Following desiccation, CS paddocks at both locations were disked (approximately 6-in depth) and prepared for seeding with a section harrow. Soybean varieties planted at CPBES and PRU were Innvictis A4618X with Roundup Ready 2 Xtend technology (Innvictis Crop Care, LLC) and Pioneer P53A67X with Roundup Ready 2 Xtend technology (Corteva Agriscience), respectively. At CPBES, planting was accomplished using a no-till vacuum planter on 30-in row spacing (1750 MaxEmerge Plus VacuMeter; John Deere) equipped with spike-toothed row cleaners (Martin-Till) and wave coulters, along with 20-pt dimple closing wheels (Martin-Till) for residue management. At PRU, planting was accomplished using a no-till 8.5-in twin row vacuum planter set on 38-in row spacing (1705 Twin Row MaxEmerge; John Deere). Target populations at both locations was 120,000 plants ac^{-1}.

Soil fertility for soybeans was managed according to routine soil analysis from each location and were based on recommendations from the Mississippi State University Soil Testing Laboratory. At CPBES, 120 and 90 lb K_2O ac^{-1} of muriated potash (0-0-60) were applied in year 1 and 2, respectively, as split applications (50/50). The first application was made at VC, with the second application between R2 and R3 growth stages. At PRU, a single application of 60 lb P_2O_5 ac^{-1} and 90 lb K_2O ac^{-1} was applied as triple superphosphate (0-46-0) and potash at planting for both years.

Pest control varied between locations. At CPBES, a pre-emergent herbicide application (2.0 pt ac^{-1} of *S*-metolachlor [4.28 lb a.i. gal^{-1}]; fomesafen [0.84 lb a.i. lb^{-1}] + 1 qt ac^{-1} of glyphosate [4.0 lb a.i. gal^{-1}]) was made immediately following planting, followed by one in-season application (12.8 oz ac^{-1} dicamba [5 lb a.i. gal^{-1}] + 1 qt ac^{-1} glyphosate [4 lb a.i. gal^{-1}]). A mid and late season insecticide application was made to control kudzu bugs and red banded stinkbugs, respectively (1 lb ac^{-1} acephate [90% a.i. by weight] + bifenthrin (5.2 oz ac^{-1} [2 lb a.i. gal^{-1}]). Once plants reached harvest maturity, a desiccant was applied to accelerate drying and uniformity at harvest (11 oz ac^{-1} of paraquat dichloride [2.7 lb a.i. gal^{-1}]). At PRU, a pre-emergent application (1.3 pt ac^{-1} of S-metolachlor [4.28 lb a.i. gal-1] + 1 qt ac^{-1} glyphosate [4 lb a.i. gal^{-1}]) was followed by a single in-season application (12.8 oz ac-1 dicamba [5 lb a.i. gal^{-1}] + 1 qt ac^{-1} glyphosate [4 lb a.i. gal^{-1}]). At PRU, a mid and late season insecticide application was made to control fall armyworms, soybean looper, and black cutworm (1.92 oz ac^{-1} of lambda-cyhalothrin [2.08 lb a.i. gal^{-1}] + 8 oz ac^{-1} of methoxyfenozide [2 lb a.i. gal^{-1}]). Insecticide applications at PRU were tank mixed with an additional application of glyphosate (1 qt ac^{-1} [4 lb a.i. gal^{-1}]). No desiccants were used at PRU. Pesticide applications for each site were the same for both years.

Soybean stand counts were conducted at the V2 growth stage (six random locations within each paddock at respective row lengths for each row spacing used by location). Total grain yield was measured by harvesting six, two-row-by-30-ft plots within each paddock using a plot combine (SPC-40; Almaco) equipped with an on-board moisture and weighing system (Seed Spector LRX; Almaco). Seed moisture, test weight, and total bu ac^{-1} were calculated for each plot.

Statistical Analysis

All statistical analysis was conducted using analysis of variance (ANOVA) in SAS (SAS Institute, 2013). The procedure PROC GLIMMIX was used to determine differences between the fixed effect of treatment system (CS, CC, and GC), while paddock (experimental unit; replication) and growing season (year) were considered random effects. Due to inherent differences between location (i.e. planting date, planting method, row spacing, etc.), data was analyzed by location. Mean cover crop characteristics (FM, RES, CP, and TDN) and animal performance (AD, ADG, and GAIN) values were used to generate economic comparisons between treatments, within each location. Soybean production (stand counts and grain yield) was compared across all treatment systems. The choice of the covariance matrix was made using the Akaike information criterion (AIC), while normality of the model residuals was checked to determine if data transformation was necessary. Treatments were considered different using PDIFF in SAS by t-test and Tukey's protected least significant difference (LSD) and differences were considered significant at 0.05 probability level.

Crop Yield and Animal Production

Forage samples were collected at the beginning of each grazing cycle, with total FM values being the sum (cumulative) of each of these sampling dates. Cumulative mean FM for cereal rye was 5,077 and 3,094 lb DM ac^{-1}, for CPBES and PRU respectively (**Table 2** and **3**). At CPBES, cereal rye was NT drilled into existing soybean crop residue, compared to broadcast planting at PRU. Typically, cereal rye establishment by broadcasting into prepared seed beds yields greater FM and enhanced subsequent animal performance. However, preexisting soybean residue contributed to delayed emergence at PRU, resulting in lower FM than anticipated. Nutritive values for samples collected at CPBES were 23.4% and 54.8% for CP and TDN, respectively. At PRU, mean CP and TDN was 12.6% and 53.3%, respectively. To meet the nutritional requirements for growing heifer calves (600 lb hd^{-1}), it is recommended to provide feedstuffs that are 13.6% CP and 75% TDN for a target ADG of 2.5 lb hd^{-1} d^{-1} and expected 1,100 lb hd^{-1} at finishing. The intended use of the animals used in this trial were for breeding stock replacements, however the targeted rate of gain and the nutritive values of the cover crop (cereal rye) was inadequate at PRU, particularly from an energy standpoint (TDN). To achieve pubertal status, or finishing weight recommendations, the addition of a concentrated source of energy (i.e. shelled corn or soybean hulls) should be considered to achieve these goals.

Animal performance was calculated by location by assessing AD, ADG, and GAIN (**Table 2** and **3**). At CPBES, mean AD for GC paddocks was 52-d, compared to only 10-d at PRU. The availability of cover crop FM was the limiting factor in AD at PRU. Grazing days typically range between 45-120-d depending on species, soil texture, and stocking rate. Previous trials conducted at CPBES with similar stocking rates reported AD of 48-d when grazing an oat cover crop. Average daily gain was 2.99 and 1.16 lb hd^{-1} d^{-1} at CPBES and PRU, respectively. Lower ADG at PRU is a direct result of lower FM and nutritive values (CP and TDN) of cereal rye cover crop. Typical ADG for stocker cattle (heifers and steers) grazing small grains in the southeastern USA ranges from 1.5 to 3.0 lb hd^{-1} d^{-1} without additional supplementation. Total GAIN is the combination of AD and ADG and is directly impacted by forage availability and stocking rate. GAIN was 306 and 78 lb ac^{-1} at CPBES and PRU, respectively. Others have reported a range of values between 277-306 lb ac^{-1} for fine sandy loam pastures established with small grains in northern Alabama. At PRU, AD, ADG, and subsequent GAIN was expected to be lower due to less available forage which is a combined result of establishment technique and the inherent nature of heavier soils in that area.

Soybean crop performance was assessed by plant population and grain yield within each location by system treatment (**Table 2** and **3**). At CPBES, no differences were observed by treatment. Stand counts were 92, 88, and 87,000 plants ac^{-1} for CS, CC, and GC treatments, respectively. At PRU, stand counts in CS paddocks (123,000 plants ac^{-1}) were greater than CC (98,000 plants ac^{-1}) and GC (99,000 plants ac^{-1}) paddocks. Differences in grain yield were observed at CPBES, with GC paddocks (54.6 bu ac^{-1}) having greater grain yield than CC paddocks (48.6 bu ac^{-1}). At PRU, the presence of a cover crop (57.0 bu ac^{-1}) in combination with grazing resulted in the lowest grain yield (46.1 bu ac^{-1}). There was not a direct relationship between plant population and grain yield at PRU. Population counts for the CC and GC treatments were similar, yet mean grain yields were greater for CC than GC paddocks. Soil compaction from cattle tramping has been attributed to lower grain yields in crops where cover crops have been grazed. However, these impacts have been considered minimal, and the positive attributes of implementing grazing on crop ground outweighs slight reductions in crop yields.

Objective 2: Monitor the change in soil physical, chemical, and biological properties during each phase of production.

Soil Sample Collection

Grid sampling was utilized to separate each paddock into 9 individual subplots, creating 81 total subplots at each location. Sampling was conducted at CPBES and PRU prior to cover crop planting in the fall and prior to soybean planting in the spring each year. Soil bulk density, moisture, and penetration resistance were taken at each sampling point. Bulk density was determined by collecting a 5.53 in^3 core sample using a 4 in^2 bulk density cylinder placed on the end of a 60” steel rod. The cylinder was driven into the soil via slide hammer atop the rod. The collected sample was placed into a sampling box, weighed, and dried at 140°F for 72-hrs. Following drying, the samples were removed from the drier and the dry weight of the samples was taken. Soil moisture was taken using a FieldScout TDR 350 moisture meter (Spectrum Technologies, Inc.), returning a volumetric water content (VWC%) value interpreted as a percentage. A composite soil sample was gathered by using a 2-1/2” open face soil auger to retrieve a core sample at an 8-inch depth across a block of three sampling sites that were then combined to create a 231 in^3 composite sample. Three composite samples were collected from each paddock, creating 54 total composite samples at each sampling date. Penetration resistance was measured using a digital dynamic cone penetrometer. At each sampling site, penetration resistance was recorded between 0”- 4”, 4”- 8” and 8”- 12” depths in values of pounds per square inch (PSI).

Soil Analysis

Composite soil samples were sent to the Cornell Soil Health Lab at Cornell University for analysis. Assessments carried out by this lab include analysis of physical, biological, and chemical characteristics. Physical analysis included water holding capacity, surface hardness (from penetrometer readings), and aggregate stability. The biological characteristics were organic matter, soil protein, soil respiration, and active carbon. Chemical analysis included determination of soil pH, extractable P and K quantities, and minor element presence.

Water holding capacity of the soil was assessed using protocols developed by Reynolds and Topp (2008). A portion of each soil sample was placed on two different ceramic plates. These plates were then put into pressure chambers, one which reaches 10 kPa to remove water from the sample to field capacity and the other reaching 1500 kPa to remove water to permanent wilting point. Once the soils achieved field capacity and permanent wilting point, they were weighed, dried in an oven at 221°F overnight, and then weighed again. The difference of the wet weight soil (field capacity or permanent wilting point) and the dry weight soil determined the amount of water in each sample. These calculations were then used to determine the amount of water lost between field capacity and the permanent wilting point of each sample, giving the water holding capacity.

Aggregate stability was determined by air-drying the soil and shaking it through a 2.0-mm and 0.25-mm sieve on a Tyler Coarse Sieve for 15-sec. A 30-g sub-sample of the 0.25-2.0mm aggregates were dispersed across an 8" by 0.25-mm sieve. The sieve was placed 20" beneath a rainfall simulator that applies drops of water which are 4.0-mm in diameter. This rainfall simulation was carried out for 5-min, resulting in the application of 0.5" of water to the soil. The entire sieve was subjected to 0.74 J of energy from the rainfall simulation equivalent to 15 water drops sec^{-1}. Throughout this process, the soil separated into slaked material that fell through the sieve and stones that remain atop the sieve. The slake and stones were dried and weighed following the addition of water. The stable soil aggregate fraction was calculated by adding the total of the slaked material (Wslaked) and the total stones (Wstones), then subtracting from the total weight of the aggregates prior to the test (Wtotal). This calculation (Wstable) is divided by the Wtotal and the result was the quantitative value of water stable aggregates (WSA) of the soil.

To measure the total organic matter content, the soil was dried at 221°F until all water had been removed from the sample. The sample was then placed in a furnace at 932°F for 2-hr to incinerate all carbonaceous material in the sample. Following incineration, the remaining material was weighed. Subtracting the remaining weight from the initial weight determined the total mass lost. This mass was converted into a percentage to provide the % loss on ignition (%LOI). LOI value is then converted to % organic matter (OM) using the equation %OM = (%LOI * 0.7) – 0.23.

Evaluation of the protein content of the soil was carried out using the autoclaved citrate extractable (ACE) protein index. This test began by placing 3-g of soil into a pressure and heat stable glass tube along with 24-ml of a 20-mM sodium citrate buffer solution and shaken for 5-min at 180 rpm. These samples were then autoclaved for 30-min at 250°F and 15 psi, followed by a cooling period. A 2-ml portion of the cooled sample was removed and placed into a microcentrifuge tube and centrifuged at 10,000 x gravity for soil particle removal. A portion of this centrifuged sample was extracted and used to perform a standard colorimetric protein quantification assay for determination of protein content of the extraction.

Soil respiration was measured by capturing and measuring carbon dioxide that was released from soil microbes during metabolic processes. A 20-g sub-sample of air-dried soil was weighed in an aluminum boat which had been perforated with 9 pinholes in the bottom of the vessel. The vessel was placed on two staggered filter papers in the bottom of a 1-pt mason jar. A 10-ml beaker was filled with 9-ml of 0.5-M KOH and was secured to a plastic tripod and placed in the mason jar atop the soil vessel. A 7-ml aliquot of deionized water was added to the jar, being applied to the sidewall and allowed to flow down and become absorbed by the filter papers. The jar was then sealed and incubated for 96-hr. The jar was then removed from incubation and opened for electrical conductivity measurement. Electrical conductivity represents the amount of CO_2 absorbed by the 0.5-M KOH. As CO_3^{2-} concentration increases, OH^- concentration decreases as does electrical conductivity. The measured electrical conductivity of the solution following incubation was compared with that of the KOH solution prior to incubation. The difference in these two measurements quantifies the amount of CO_2 respiration from the soil sample.

Active carbon was measured by first air-drying and sieving to 2-mm a portion of the soil sample. A 2.5-g subsample was placed into a 50-ml tube, followed by addition of 18-ml of distilled water and 2-ml of 0.2-M $KMnO_4$ solution. The tube and its contents were shaken for 2-min at 120 rpm, oxidizing the active carbon within the soil. The sample settled for 8-min. After resting, 0.5-ml of the soil-water-$KMnO_4$ solution was removed from the tube and added to another tube containing 49.5-ml of distilled water. The combining of solution and distilled water terminated the reaction. The new solution was shaken by hand for 10-sec. Sample tubes were analyzed for active carbon via spectrophotometer. Oxidation of the $KMnO_4$ by the active carbon present was represented by the loss of purple coloration in the solution. Absorbance of 1-M MnO_4 was understood to occur with the oxidation of 0.75-M C. A colorimeter determined the amount of MnO_4 in the final solution, which was the amount of absorbance used in calculating the standard curve and active carbon. The standard curve equation used was Concentration = a + b * (absorbance). The active carbon equation used was Active C (mg/kg) = [0.02 mol/L – (a + b * absorbance)]*(9000 mg C/mol) * (0.02 L solution/0.0025 kg soil).

Soil pH was measured by creating a slurry consisting of two parts by volume of deionized water and one part by volume of soil sample. After mixing the slurry, the sample was allowed to settle for 20-min. Once settled, the solution was stirred again for 15-sec, and the pH electrode probe was placed into the solution using a lignin pH robot. The pH of the sample was determined from the reading of the probe and evaluated based on the 14.0-unit pH scale.

Macronutrient and micronutrient evaluation in the soil sample began by mixing 5-ml of soil, air dried at 122°F, with 20-ml of Modified Morgan's solution in a 125-ml Erlenmeyer flask, creating a 1:4 ratio of soil to solution. The Erlenmeyer flask was sealed and shaken for 15-min. The contents of the flask were then poured onto a coarse filter paper that had been placed in a wide-mouth funnel above a receptacle. The receptacle held the filtered soil-solution mixture. A Thermo Elemental IRIS Intrepid ICP-AES spectrophotometer was used for ICP analysis of Ca^{2+}, Mg^{2+}, K^+, P^{3-}, Al^{3+}, Mn^{2+}, and Fe^{3+}. Nutrient quantities were then reported as ppm (mg nutrient/ kg soil).

Mean values for soil physical, chemical, and biological characteristics can be found in **Table 4**. Analysis was compared by treatment within each location. At CPBES, surface hardness was significantly greater for the GC (353 PSI) treatment, followed by CC (256 PSI), and CS (222 PSI). These values were determined using soil penetrometer readings (compaction) at varying depths. The greater compaction in grazed treatments did not impact subsequent soybean yield at CPBES, as GC was similar to CS. Mean OM was greater for CC (3.51%), compared to CS (3.02%) and GC (3.01%). Phosphorus was greater for CS (20.0 ppm), compared to CC (5.9 ppm) and GC (12.2 ppm). At PRU, like CPBES, mean OM concentrations were greatest for CC paddocks. Mean total C, total N, and P were all lower for the CS paddocks compared to the other two treatments.

Objective 3: Assess the economic productivity throughout each phase of production.

Average returns for each cropping system (CS, CC, and GC) were determined by calculating revenue and costs associated with each practice/input for each system. Costs included pesticides, fertilizer, seed, custom application rates, management practices (i.e. tillage, planting, etc.), and opportunity costs for capital. For the GC treatment, cattle revenue was determined by multiplying mean GAIN (lb ac^{-1}) by mean value of gain ($ lb^{-1}). Value of gain was calculated as the difference between the end value of cattle (final price multiplied by final weight) and the beginning weight of cattle (initial price multiplied by initial weight) divided by GAIN. Value of gain was determined using average sale prices from archived (2021 – 2023) Mississippi statewide auction reports for similar sex and weight cattle. Average auction prices from an 8-wk period surrounding the purchase and sales dates (4-wk prior and 4-wk post purchase/sell) were used. Dates for these weeks were determined by the initial grazing dates for each trial period, and when cattle were removed from their last grazing event. For the cattle value calculation of this particular system (GC), only purchase and sales price were considered. Other costs, including immunizations, parasite control, marketing, transportation, death loss, and infrastructure (i.e. fencing, water, labor, etc.) were not included in this analysis. These costs, though extremely important to a producer's overall profitability, can vary considerably across integrated crop-livestock systems. Rather than include an estimate within this analysis, we strongly encourage producers to consider their own anticipated costs for these factors.

Soybean revenue was calculated by multiplying 2-yr (2022 and 2023) mean yield (bu ac^{-1}) by location by the average value of soybean ($ bu^{-1}) based on Mississippi average prices from 2022 and 2023. All inputs and opportunity costs were used from the Mississippi Forage Planning Budget, 2024, and the Mississippi Soybean Planning Budget, 2024 (**Table 1**).

Economic Profitability

Total costs for each treatment by location are found in **Tables 2** and **3**. Cover crop costs varied by location ($171.18 ac^{-1} at CPBES; $144.71 ac^{-1} at PRU) and can be attributed by planting method. The cost for no-till drilling cover crop seed was $33.04 ac^{-1}, compared to broadcast seeding (spin spreader) at $5.05 ac^{-1} (**Table 1**). Soybean cost varied by treatment within each location. This variation was attributed to grain hauling costs that were incurred based on mean grain yield for each treatment. Base cost minus grain hauling was \$273.11 and \$304.86 ac^{-1} for CPBES and PRU, respectively. Total production costs [cover crop + soybean (including grain hauling calculation) + interest on operating capital] at CPBES were \$286.26, \$285.26, and \$286.88 ac^{-1}, for the CS, CC, and GC treatments, respectively. At PRU, production costs were \$339.32, \$480.93, and \$477.98 ac^{-1} for the CS, CC, and GC treatments, respectively.

Soybean revenue was calculated using the Mississippi Soybean Planning Budget statewide average price (\$12.67 bu^{-1}). This price was determined by adding the futures contract price for soybeans for Nov 2023 plus the basis (\$0.01). The basis was the cash price minus the futures contract price for the stated contract month (Nov) and the reported basis was the daily average from 2009 to 2020 for soybeans at Greenville, MS. Mean soybean revenue was \$662.64, \$615.76, and \$691.78 ac^{-1} at CPBES and \$867.89, \$722.19, and \$584.08 ac^{-1} at PRU for the CS, CC, and GC treatments, respectively.

Cattle revenue was determined for GC paddocks by location and was calculated by multiplying cattle value of gain (\$ lb^{-1}) by GAIN (lb ac^{-1}). Value of gain was calculated using Mississippi weekly livestock auction reports. Mean beginning and end prices during the 8-wk period (4-wk pre-grazing/4-wk post-grazing) were based on the grazing season for each location. At CPBES, initial purchase price during the Dec-Jan period was \$129.67 cwt^{-1} for 600-700 lb hd^{-1} heifers. Sale price for the Mar-Apr period used for analysis was \$122 cwt^{-1} for 900-1,000 lb heifers. At PRU, the mean purchase price for Dec-Feb (2022) and Mar-Apr (2023) was \$164 cwt^{-1} for 500-600 lb hd^{-1} heifers and the sale price was \$166 cwt^{-1} for the same weight class heifers during the Apr-May period. Mean purchase and sale weight of heifers was 1,342 and 1,908 lb ac^{-1} at CPBES, and 1,903 and 1,983 lb ac^{-1} at PRU. This resulted in a mean purchase and sale price of \$1,740.82 and \$2,334.66 ac^{-1} at CPBES, and \$3,133.30 and \$3,292.59 ac^{-1} at PRU. The difference in sale price minus purchase price (cattle total revenue) was \$593.84 and \$160.29 ac^{-1} for CPBES and PRU, respectively. This value was then divided by GAIN, resulting value of gain of \$1.94 and \$2.04 lb^{-1} for CPBES and PRU, respectively.

Total revenue was determined by adding soybean revenue with cattle revenue (when applicable; **Tables 2** and **3**). Total revenue at CPBES was \$662.64, \$615.76, and \$1,285.62 ac^{-1} for CS, CC, and GC treatments, respectively. At PRU, total revenue was \$867.89, \$722.19, and \$744.38 ac^{-1} for the same treatments. Net returns above soybean and cover crop costs (revenue minus costs) was \$360.41, \$143.35, and \$811.59 ac^{-1} for CS, CC, and GC treatments, respectively, at CPBES. At PRU, these same treatment net returns were \$528.58, \$241.26, and \$266.40 ac^{-1}. As mentioned in the Economic Assessment section above, the only cattle production costs included in these returns were the cattle purchase costs only.

Results from these field trials comparing conventional soybean production with and without a grazed cereal rye cover crop on two distinctly different soil types indicate that the combination of no-till soybeans and a grazed cereal rye cover crop more than double net returns per acre on a fine sandy loam soil. However, as observed at PRU, the same combination of no-till soybeans and grazed cover crop resulted in substantially lower revenue than conventional soybean production on a heavy clay, poorly drained soil. On these soils, it is recommended to apply conventional methods to achieve the greatest soybean yields and net returns. However, on coarse-textured, well-drained soils, there are tremendous opportunities for increased revenue through the implementation of integrated crop-livestock systems. Our research contributes to the growing precedent of research that demonstrates the economic impact diversification of agricultural enterprises, particularly cattle and row crops, can have in the Coastal Plain region of the Southeast. The incorporation of cattle into cover cropping systems has been shown to more than offset the costs of adopting cover crops and can generate additional revenue for the landowner. Future work should continue to consider the ramifications of these systems on soil health, and perhaps the inclusion of crop rotation and organic/conventional practices as a component of the integrated crop-livestock approach. As always, long-term data collection would be extremely beneficial in determining the sustainability of these systems over time.

Impacts and Benefits to Mississippi Soybean Producers

Approximately 700,000 acres of cool-season annual forages are planted across Mississippi for livestock production. Nearly 23% of that acreage (154,433 acres) is planted in small grains such as oats, cereal rye, and wheat. Traditionally, many stocker cattle operations utilize these species in a conventional setting through tillage and seed bed preparation. During the fallow season (summer months), these fields are either re-established in a summer annual, such as crabgrass, pearl millet, or forage sorghum, or allowed to rest until fall for the next grazing season. Tremendous opportunities exist for these producers to expand upon their current operations by planting soybeans when cattle are not present, in order to generate additional revenue by adding another crop season.

From a row-crop perspective, small grains are excellent choices for use as cover crops in protecting soil from erosion, nutrient scavenging, increasing organic matter, and enhancing soil structure in no-till settings. However, costs associated with planting cover crops often outweigh potential benefits. Utilizing livestock may help account for these costs, and aid in nutrient cycling by returning undigested nutrients back into the soil profile through urine and manure. Partnering row crop and beef cattle enterprises has the potential to increase soybean acreage across the state, while simultaneously providing additional revenue outlets for soybean and cattle producers.

Table 1. Costs for crop inputs, including fertilizer, herbicides, seed, and equipment operation rates for applications, planting, harvesting, and hauling.

Input	Description	Unit	Price
Cover crop			
Urea[a]	Solid (46-0-0)	$ lb^{-1}	0.41
Glyphosate	3 lb a.e.	$ pt^{-1}	5.38
Small grains seed		$ lb^{-1}	0.89
Spin spreader[b]	5-ton	$ ac^{-1}	6.57
Spray (broadcast)[b]	40-ft	$ ac^{-1}	5.05
No-till grain drill[b]	10-ft	$ ac^{-1}	33.04
Soybean crop			
Potash	Solid (0-0-60)	$ lb^{-1}	0.36
Phosphorus	Solid (0-46-0)	$ lb^{-1}	0.39
Soybean seed	RR2X	$ lb^{-1}	1.15
Metolachlor		$ pt^{-1}	8.23
Fomesafen		$ pt^{-1}	7.34
Dicamba		$ pt^{-1}	5.32
Glyphosate	3 lb a.e.	$ pt^{-1}	5.38
Paraquat		$ oz^{-1}	0.23
Acephate	90%	$ lb^{-1}	8.25
Bifenthrin		$ oz^{-1}	0.56
Lambda		$ oz^{-1}	0.39
Methoxyfenozide		$ oz^{-1}	1.99
Disk + incorporate	14-ft	$ ac^{-1}	18.69
Spin spreader[b]	5-ton	$ ac^{-1}	6.57
Spray (broadcast)[b]	40-ft	$ ac^{-1}	5.05
Plant (rigid)[b]	6R-30	$ ac^{-1}	18.69
Plant (twin-row)[b]	8R-30/40	$ ac^{-1}	22.81
Harvest[b]	22-ft flex	$ ac^{-1}	43.49
Grain cart[b]	500-bu	$ ac^{-1}	3.81
Hauling[b]		$ bu^{-1}	0.27

[a]Prices were obtained from 2023 Mississippi statewide averages (Maples et al., 2023a; Maples et al., 2023b).
[b]Includes operator labor at $17.94 hr^{-1} and diesel fuel at $3.44 gal^{-1}.

Table 2. Cover crop, animal, soybean, and economic performance for conventional soybean (CS), cereal rye cover crop + no-till soybean (CC) and grazed cereal rye cover crop + no-till soybean (GC); Coastal Plain Branch Experiment Station (CPBES), Newton, MS (2021-2023).

Variable	System		
	CS	CC	GC
Cover crop			
FM[a], lb DM ac^{-1}	---	---	5,077
CP, %	---	---	23.4
TDN, %	---	---	54.8
Animal			
AD, d yr^{-1}	---	---	52
ADG, lb hd^{-1} d^{-1}	---	---	2.99
GAIN, lb ac^{-1}	---	---	306
Soybean			
Population, plants 1/1000 ac^{-1}	92	88	87
Grain yield, bu ac^{-1}	52.3 ab	48.6 b	54.6 a
Economics			
Cover crop cost, $ ac^{-1}	---	171.18	171.18
Soybean cost, $ ac^{-1}	286.26	285.26	286.88
Interest on operating capital, $ ac^{-1}	15.97	15.97	15.97
Total crop production cost, $ ac^{-1}	302.23	472.41	474.03
Soybean revenue, $12.67 bu^{-1}	662.64	615.76	691.78
Cattle value of gain, $ lb^{-1}	---	---	1.94
Cattle revenue, $ ac^{-1}	---	---	593.64
Total revenue, $ ac^{-1}	662.64	615.76	1,285.62
Net return above soybean and cover crop production costs, $ ac^{-1}	360.41	143.35	811.59

Note. Lowercase letters denote significant differences at $\alpha = .05$.

[a]FM, forage mass; CP, crude protein; TDN, total digestible nutrients; AD, animal days; ADG, average daily gain; GAIN, gain per acre.

Table 3. Cover crop, animal, soybean, and economic performance for conventional soybean (CS), cereal rye cover crop + no-till soybean (CC) and grazed cereal rye cover crop + no-till soybean (GC); Prairie Research Unit (PRU), Prairie, MS (2021-2023).

Variable	System		
	CS	CC	GC
Cover crop			
FM[a], lb DM ac^{-1}	---	---	3,094
CP, %	---	---	12.6
TDN, %	---	---	53.3
Animal			
AD, d yr^{-1}	---	---	10
ADG, lb hd^{-1} d^{-1}	---	---	1.16
GAIN, lb ac^{-1}	---	---	78
Soybean			
Population, plants 1/1000 ac^{-1}	123 a	98 b	99 b
Grain yield, bu ac^{-1}	68.5 a	57.0 b	46.1 c
Economics			
Cover crop, \$ ac^{-1}	---	144.71	144.71
Soybean, \$ ac^{-1}	323.35	320.25	317.30
Interest on operating capital, \$ ac^{-1}	15.97	15.97	15.97
Total crop production cost, \$ ac^{-1}	339.32	480.93	477.98
Soybean revenue, \$12.67 bu^{-1}	867.89	722.19	584.08
Cattle value of gain, \$ lb^{-1}	---	---	2.04
Cattle revenue, \$ lb^{-1}	---	---	160.29
Total revenue, \$ ac^{-1}	867.90	722.19	744.38
Net return above soybean and cover crop production costs, \$ ac^{-1}	528.58	241.26	266.40

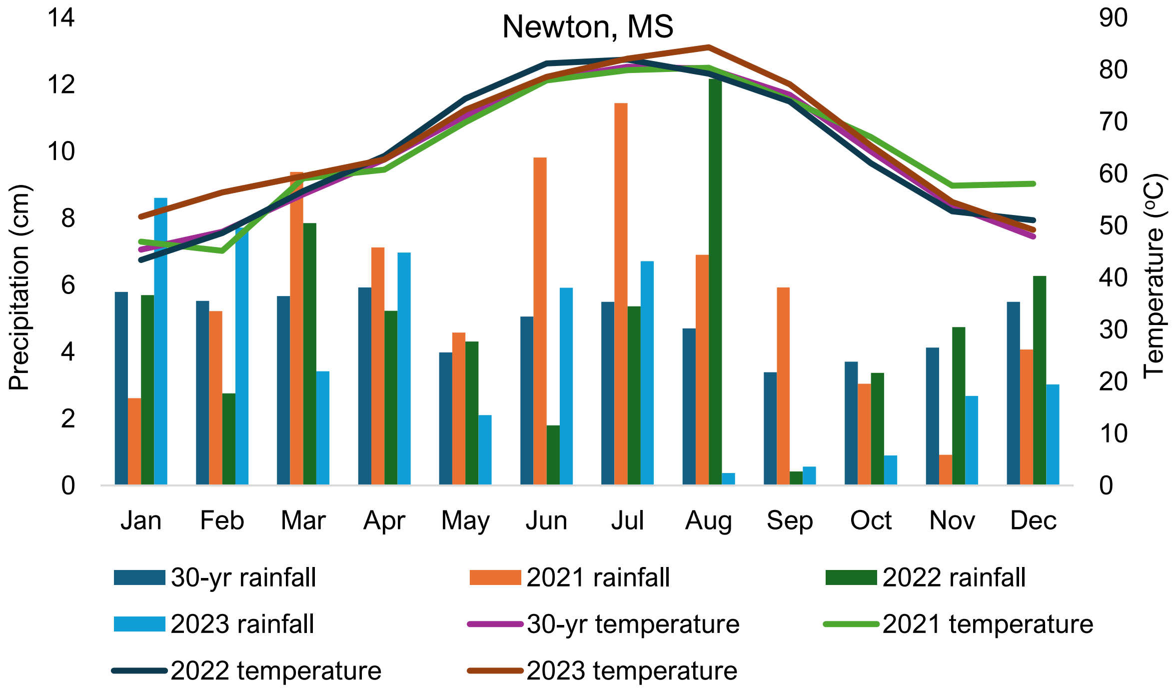
Note. Lowercase letters denote significant differences at $\alpha = .05$.

[a]FM, forage mass; CP, crude protein; TDN, total digestible nutrients; AD, animal days; ADG, average daily gain; GAIN, gain per acre.

Table 4. Physical, biological, and chemical characteristics for soil samples collected across four sampling dates at the Coastal Plain Branch Experiment Station (CPBES), Newton, MS and the Prairie Research Unit (PRU), Prairie, MS; 2021-2023.

Variable	Unit	CPBES			PRU		
		CC[a]	CS[a]	GC[a]	CC	CS	GC
Physical							
Aggregate stability	%	18.5 a[b]	14.1 b	18.4 a	67.6	66.6	66.7
Water holding capacity	(g H_2O g^{-1} soil)	0.21 b	0.22 a	0.21 b	0.25 a	0.24 ab	0.24 b
Bulk density	(g cm^{-3})	1.21 ab	1.24 a	1.19 b	1.26	1.24	1.27
Surface hardness	PSI	256 b	222 c	353 a	164 b	180 ab	192 a
Biological							
Active C	ppm	583 a	521 b	552 ab	587 a	547 b	572 a
Organic matter	%	3.51 a	3.02 b	3.01 b	5.84 a	5.44 c	5.65 b
ACE protein	mg g^{-1} soil	6.73	6.27	6.62	4.89	4.68	4.61
Respiration	mg CO_2 g^{-1} soil	0.53	0.50	0.51	0.75	0.67	0.76
Chemical							
pH		6.07 b	6.29 a	6.17 ab	6.54	6.58	6.73
Total C	%	1.64	1.45	1.61	2.98 a	2.66 b	2.99 a
Total N	%	0.18	0.17	0.18	0.25 a	0.22 b	0.24 a
P	ppm	5.9 c	20.0 a	12.2 b	2.4 a	1.8 b	2.3 a
K	ppm	71.0 a	61.9 ab	52.8 b	91.6 b	89.2 b	123.9 a

[a]CS – conventional soybean; CC – no-till soybean + cereal rye cover crop; GC – no-till soybean + grazed cereal rye cover crop.
[b]Lowercase letters denote significant differences at $\alpha = 0.05$ within a row by location.



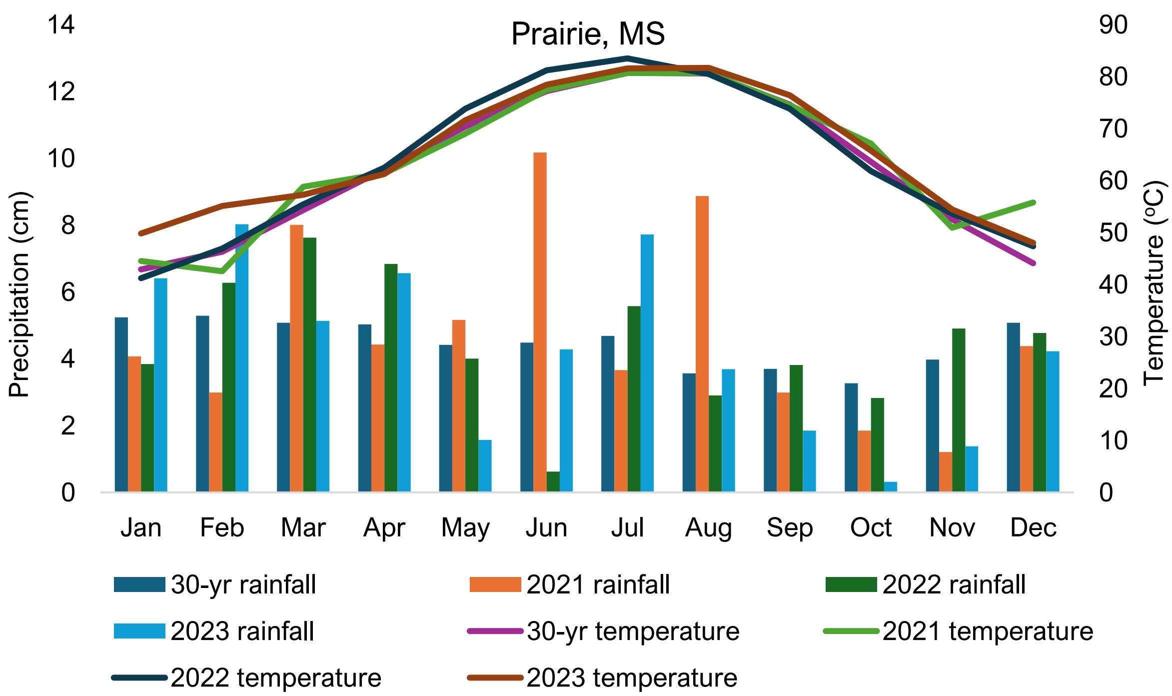


Figure 1. Total month precipitation (in) and mean monthly temperature (°F) with 30-yr historical means for Newton and Prairie, MS; 2021-2023.