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The effects of grazing cover crops on animal performance, soil characteristics, and subsequent soybean production in east-central Mississippi

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Integrated crop-livestock systems (ICLS) incorporate cropping systems and livestock production by grazing cover crops. With a growing awareness in recent years regarding agricultural sustainability, these systems have begun to be re-introduced into the southeastern U.S. This study evaluated cover cropping systems under grazed no-till (GNT), un-grazed no-till (UNT), and un-grazed conventional tillage (UCT) management, in Mississippi. Beef cattle (*Bos spp.)* performance was significantly less in the cover crop treatment of oats (*Avena sativa*) + crimson clover (*Trifolium incarnatum*) + radish (*Raphanus sativus*; OCR) in both average daily gain (ADG; 3.03 lb hd^{-1} d^{-1}) and total gain ac^{-1} (GAIN; 346 lb ac^{-1}). Soybean (*Glycine max*) yield was unaffected by cover crop treatment and tillage. The lowest expected economic return was generated by OCR ($749.31 ac^{-1}). Soil penetration resistance was unaffected by the influence of grazing. The greatest concentrations of soil organic carbon (1.44%) and soil nitrogen (0.20%) were observed in GNT.

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CHAPTER I

INTEGRATED CROP-LIVESTOCK SYSTEMS IN THE SOUTHEASTERN U.S.

Integrated crop-livestock systems (ICLS) have been utilized in agriculture dating back to early civilizations. These systems were designed to produce a wide variety of products that helped sustain human and livestock nutritional demands (Russelle et al., 2007). This type of subsistence farming allowed for small tracts of land to have multiple species of crops grown, while simultaneously supporting livestock. Integrated crop-livestock systems can be defined several ways depending on the specific practices utilized to incorporate livestock and cash crops into one agricultural system. In general, ICLS are a form of sustainable intensification of agriculture that rely on synergistic relationships between plants and animals which bolster critical agroecosystem processes (Peterson et al., 2020). Regardless of how the practice is implemented, any farming system involving both the production of a cropping system and livestock can be considered an ICLS. An example of early forms of ICLS observed in the U.S. would be a farmer producing their own feed, through cropping systems, for the livestock raised on that same property. Before the modern industrialization of the U.S. in the 20th century, this farming method of integrating both crops and livestock on the same land base was commonly practiced (Franzluebbers, 2007).

Recently, there has been a growing interest in ICLS in the United States (U.S.). This focus stems from the need to generate more revenue, increase soil health attributes, and address agro-ecosystem resiliency. In addition, the desire to generate greater crop yields for sustaining growing populations, with declining ag labor and infrastructure, has increased the popularity of ICLS. Since 2012, U.S. land in farms decreased by 14,310,081 ac, to 900,217,576 total ac in 2017 (USDA-NASS, 2017). Regarding U.S. population trends, a population increase of 5.96% from April 1, 2010, to July 1, 2018, was observed (U.S. Census Bureau, 2018). Overall employment of agricultural workers is projected to grow 1% from 2019 to 2029, slower than all other occupations (U.S. Bureau of Labor Statistics, 2021). Employment growth is expected to be tempered from the use of technology and more sustainable productivity. These trends illustrate the importance and need for the utilization of sustainable agricultural systems in the U.S.

Incorporating ICLS onto modern agriculture landscapes is different from the specialized agricultural systems commonly practiced in the U.S. today. Within the last century many producers have become specialized in their crop or livestock production to meet the needs of the growing global population (Kumar et al. 2019). However, this intensified agricultural production can lead to degradation of soil, and unsustainable resource use (Tilman et al., 2001; Herrero et al., 2009; Reganold et al., 2011). Integrated crop-livestock systems are an alternative to fields being left fallow during the off-season that will allow for increased productivity (Ambusa et al., 2018). It can be expected that these systems will enhance profitability of a farm, while making it more environmentally sustainable (Russelle et al., 2007).

Soil health is a topic of continued interest in the U.S., particularly in regard to fertility and biological activity. Soil health can be defined simply as the capacity of soil to function (Karlen et al., 1997). Soil health, referred to as soil quality by some, is the overall capacity of the soil to function as a system of living organisms, requiring management and conservation (Doran and Zeiss, 2000). Soil health is the direct indicator of sustainable management of the land (Karlen et al., 1997) and is dependent upon the maintenance of 4 key functions: 1) the maintenance of soil structure, 2) regulation of diseases and pests, 3) cycling of nutrients, and 4) carbon sequestration (Kibblewhite et al., 2008). The productivity of the soil can be evaluated in perspective to the growth of the crops being produced, as soils must contain appropriate properties that support abundant plant growth for the crop to be successful. Several of these properties, such as nitrogen fixation and organic matter contribution, can be maintained through the use of cover crops.

Cover crops have been identified as crucial components to ICLS. According to a survey by Sustainable Agriculture Research and Education (SARE), survey respondents reported a 25% increase in acreage planted in cover crops from 485,633 ac in 2015 to 606,760 ac in 2016 (SARE, 2017). The general concept behind the use of cover crops is to improve the soil health of a field, by improving water infiltration, increasing soil nitrogen content, improving aggregate stability, etc. in hopes to ultimately improve grain yield, or lower production costs.

Cool-season cover crops are utilized in the southeastern U.S. in the winter and spring between summer cash-crop rotations (Nov to Apr). Cool-season cover crops can be commonly grouped into 4 basic categories: grasses [oats (*Avena sativa*), wheat (*Triticum aestivum*), annual ryegrass (*Lolium multiflorum*), etc.], legumes [crimson clover (*Trifolium incarnatum*), alfalfa (*Medicago sativa*) etc.], brassicas [radish (*Raphanus sativus*), turnips (*Brassica rapa*), etc.], and non-legume broadleaf plants [canola (*Brassica napus*), spinach (*Spinacia oleracea*), flax (*Linum usitatissimum*), etc.]. Of these categories of cover crops there are a multitude of mixtures and combinations that can be planted to fit a producer's specific needs based on their cropping system and soil health goals.

Many species of cool-season cover crops used in row crop production have also been grazed as forages by ruminants in a pasture setting. In general, cool-season grasses and legumes are high in crude protein and digestibility. In many ICLS, grazing cover crops is the means in which livestock production is incorporated into the system. The basis behind grazing cover crops is to increase the productivity of a field used in row crop production by improving soil health through the traditional benefits of cover crops used in row crop production systems, while also supplying nutritious feedstuffs for livestock. Grazing cover crops has been shown to increase animal productivity and creates an additional incentive for cover cropping as it could provide an alternative economic benefit to producers (Franzluebbers, 2007). More specifically, beef cattle producers in the southeastern U.S. could particularly benefit from grazing cover crops as it would increase the amount of available forage when warm-season pastures are unutilized.

In Mississippi, beef cattle (*Bos spp*.) production ranks 6th among agricultural commodities with over 930,000 head in inventory (USDA-NASS, 2017). Most of the feedstuffs used to feed the state's herd comes from warm-and cool-season perennial pasture grasses, such as bahiagrass (*Paspalum notatum*), bermudagrass (*Cynodon dactylon*), and tall fescue (*Festuca arundinacea*). However, there is a significant amount of acreage devoted to annual species for stocker cattle production. In these areas, favorable environmental conditions allow for cool-season forages to be grown, allowing greater weight gains at a relatively low cost from an economic standpoint. Forages high in nutrient content can provide an opportunity for an additional agricultural product that can be produced in the form of meat, as cover crops are used to generate animal weight gains (Carvalho et al., 2018). When cool-season species of cover crops are utilized as forages there is an ability to extend the length of the grazing season beyond the scope of traditional, warm-season perennial pastures (Dubeux Jr. et al., 2016). In ICLS, particularly in the southeastern U.S., cool-season forages are optimal species that can easily be adopted into row crop settings.

In Mississippi, soybeans (*Glycine max*) rank 3rd in agricultural commodities produced with over 1,9000,000 ac in production, and yields averaging 43.8 bushels per acre (non-irrigated), accounting for $1,105,093 in sales in 2017 (USDA-NASS, 2017). Cover cropping in Mississippi soybean production has primarily focused on soil retention and stabilization. However, most producers are reluctant to incorporate cover crops into traditional soybean production systems due to increased costs of establishment (Bryant et al., 2020). Due to the importance of this crop, producers in the state are constantly trying to improve their crop by increasing yields and minimizing production costs to increase economic returns. Traditionally, cover crop implementation has been focused on improving soil health, and minimizing production costs in certain scenarios, grazing cover crops could provide an added benefit to producers with immediate economic returns attained by animal weight gains, allowing for added returns in a traditional soybean cropping system.

This research project was designed to evaluate the effects that grazing cover crops has on animal performance, soil characteristics, and soybean production in the Coastal Plain region of Mississippi. In addition, an economic analysis was performed placing a monetary value on each of the systems tested. The objectives of this study are to: 1) evaluate animal performance on three cover crop systems, 2) assess forage mass and nutritive value of varying cover crop species, 3) evaluate soybean yield as impacted by grazing and cover cropping system, 4) monitor soil physical and chemical changes, 5) and determine the economic advantages within each cover cropping system.

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CHAPTER II

INTEGRATED CROP-LIVESTOCK SYSTEM EFFECTS ON ANIMAL PERFORMANCE AND SOYBEAN PRODUCTION

Impacts of Grazing Cover Crops on Animal Gain and Soybean Yield

Cool-season cover crops used in rotation with a warm-season cash crop may provide the potential for an enhanced agricultural system with conservation benefits (Reeves, 1994; Dabney et al., 2001). Cover crops prevent erosion by means of both wind (Bilbro, 1991; Unger and Vigil, 1998) and water. The soil physical environment can be improved with the use of cover crops as soil compaction can be alleviated and the susceptibility of the soil to compaction being reduced. Water infiltration, aggregate stabilization, and weed suppression are additional sought-after benefits provided by cover crops. Regarding soil nutrients, organic matter composition is improved by both above and belowground biomass and can provide nitrogen (N) benefits to subsequent crops (Blanco-Canqui et al., 2015). In integrated crop-livestock systems (ICLS) cover crops can provide a source of feed to grazing animals when utilized as a forage (Franzluebbers, and Stuedemann, 2007).

While the benefits of cover crops are widely recognized, adoption is limited in much of the U.S. (Wallander, 2013). Costs related to establishment are a primary reason for lack of implementation, as it was estimated in Alabama to cost \$65 ac^{-1} for cereal rye (*Secale cereale*) and \$48 ac^{-1} for crimson clover (*Trifolium incarnatum*) establishment (Schomberg et al., 2014). A survey indicated that while 96% of producers who used cover crops believed that soil erosion was effectively minimized and 74% felt that soil organic matter was being increased, an incentive of \$23 ac^{-1} would need to be attained for half of the respondents to use cover crops in their system (Singer et al., 2007). In order for producers to economically justify cover crop implementation, alternative sources of revenue must be realized.

Since most cover crops utilized in the southeastern U.S. have been historically used as forage crops, there is a significant amount of research that has focused on animal performance, particularly in stocker cattle systems when grazing cover crops. A study by Siri-Prieto et al. (2007) in Headland, AL was conducted evaluating oat (*Avena sativa*) and annual ryegrass (*Lolium multiflorum*) cover crop treatments, in an ICLS, when grazed by stocker cattle. Results observed were that during an 81-day grazing period, total gain per acre (GAIN) was 480 lb and 500 lb ac^{-1}, for oats and annual ryegrass, respectively. Total cost of grazing was reported to be \$78 ac^{-1} in this system, resulting in a net return of approximately \$80 ac^{-1} directly from cover crop grazing. Franzluebbers and Stuedemann (2007) found the net return over variable costs to be highly significant when comparing the management systems of grazing cover crops. Returns of \$122 ac^{-1} were attained when the cover crop was grazed, while a return of only \$25 ac^{-1} was attained when the cover crop was left un-grazed, showing great potential for producers to generate economic gains by grazing cover crops.

With the utilization of grazing animals, economic returns are a direct result of animal performance [i.e., average daily gain (ADG), GAIN, and animal days (AD)]. A 3-year study by Beck et al. (2005) in Arkansas evaluating stocker cattle performance while grazing winter annual grass mixtures observed that for all small grain treatments including oats, wheat (*Triticum* *aestivum*), and cereal rye, as well as small grain + annual ryegrass mixtures, ADG for the fall and winter months was not affected by the annual ryegrass mixtures. It was only in the spring months that an increase of 19% in ADG was seen in the cereal rye x annual ryegrass mixture when compared to the other small grain treatments (Beck et al., 2005). Pereira (2009) concluded that when grazed by steers, oats provided greater GAIN when compared to cereal rye or annual ryegrass (449.85 lb ac^{-1} vs. 379.34 lb ac^{-1} and 364.16 lb ac^{-1}, respectively). Similarly, Mullenix et al. (2012) observed that oat and annual ryegrass grown by themselves produced greater animal gains than cereal rye alone, and when planted in mixtures oats generated greater ADG than both cereal rye and annual ryegrass when grown in mixtures. Another grazing study conducted in Headland, AL (Kouka et al., 1994) compared cereal rye, cereal rye + annual ryegrass, and oats. They observed that oats and cereal rye + annual ryegrass pastures were superior to cereal rye pastures in both weight gains and profit. Of the three forage crop treatments, oats provided the best animal performance, averaging 2.23 lb hd^{-1} d^{-1} with cross-bred heifers averaging 450 lb hd^{-1} stocked at 2 hd ac^{-1} (900 lb ac^{-1}).

Animal performance when grazing cover crops is dependent upon cover crop management as nutritive value and forage availability can vary. Farney et al. (2018) evaluated 16 three-way cover crop mixtures for forage production and nutritive value. They observed that for grass production within all mixtures, oats had the greatest forage mass (FM; 1549 lb DM ac^{-1}). Timing of grazing also affects the forage parameters of cover crops as illustrated by the findings of Han et al. (2018) in which a decline in CP was observed from late winter to early spring, with cereal rye experiencing the greatest decline, falling from 24.6 % to 11.3 %.

Regarding establishment methods of cover crops and their relationship to FM produced, Franzluebbers and Stuedemann (2007) found that in a cereal rye cover crop, no-till (NT) establishment resulted in significantly greater FM in 2003 when compared to conventional tillage (CT), however, differences were not significant in subsequent years. Similarly, the number of grazing days for cereal rye was found to be greater under NT conditions than CT when averaged across years, which was related to an increased amount of FM, resulting in greater ADG (36%) in NT cereal rye compared to CT. From this research it was concluded that in ICLS subsequent crop yields are not reduced and could even be enhanced under NT management (Franzluebbers and Stuedemann, 2007).

While cover crop establishment, production, and management directly impacts economic returns related to grazing animals in an ICLS, subsequent crop production is also affected by these factors. A 3-yr cotton (*Gossypium hirsutum*) and peanut (*Arachis hypogaea*) rotation with a cereal rye or annual ryegrass cover crop treatment was conducted in Moultrie, GA (Hill et al., 2004). They observed no significant differences in crop yield when the cover crop was grazed or left un-grazed. In yrs 1 and 3 of this experiment cotton lint yield averaged 1,070 lb ac^{-1} when the cover crop was grazed and 1,159 lb ac^{-1} when left un-grazed. In yr 2, peanut yield averaged 3,657 lb ac^{-1} and 3,747 lb ac^{-1} for un-grazed and grazed cover crop treatments, respectively. A similar study conducted in Headland, AL evaluating a cotton and peanut ICLS rotation grown with oat and annual ryegrass cover crops found that under grazed conditions both cotton and peanut plant populations were greater following the oat cover crop when compared to annual ryegrass (Siri-Prieto et al., 2005). Franzluebbers and Stuedemann (2004) evaluated the subsequent grain yield of both cool- and warm-season grain cropping systems grown in rotation with a cover crop. A sorghum (*Sorghum bicolor*) grain crop following a cereal rye cover crop in yrs 1 and 3 of this study indicated no differences in grain yield between grazed and un-grazed cover crop treatments. Year 1 occurred during a significant lack of rainfall in the region, and it was suggested that differences in grain yield between CT and NT treatments were observed due to better distribution of water content in the CT system (Franzluebbers and Stuedemann, 2004). In yr 3, with ample rainfall, grain sorghum yield averaged 63 bu ac^{-1} with no differences observed between tillage or grazing treatments (Franzluebbers and Stuedemann, 2004).

In the southeastern U.S., research regarding soybean (*Glycine max*) grain yield in ICLS has been limited. However, the effects of cover crops grown in a soybean rotation has been studied extensively. Thelen and Leep (2002) studied the effects of various double cropping systems that utilized winter annual cover crops. For treatments of cereal rye, wheat (early and late cut), and no cover crop, there were no differences observed between soybean yield production (Thelen and Leep, 2002). In Mississippi, Reddy (2001) evaluated several cover cropping systems and their effects on soybean yield. While it was found that the NT + no cover crop system resulted in the greatest soybean yield, it should be noted that in this experiment treatments of a crimson clover cover crop resulted in greater soybean yield than an oat cover crop. In a study comparing the use of a tillage radish (*Raphanus sativus*) cover crop and the tillage practice of subsoiling, it was found that the tillage radish treatment reduced soybean grain yield by up to 12% (Bryant et al., 2020). It was stated that when utilizing a tillage radish cover crop as an alternative management practice to subsoiling, net returns were reduced above specified costs by up to 41% due to costs of cover crop seed and desiccation (Bryant et al., 2020). However, Acuña and Villamil (2004), found with the use of a tillage radish cover crop, differences in soybean yield were not statistically significant when compared to a treatment of no cover crop.

In Mississippi many producers operate diversified agricultural enterprises that entail both row crops and beef cattle. The integration of these systems onto a single land base, by grazing cover crops, has the potential to economically justify cover crop adoption. However, with the incorporation of cattle into a row crop setting, concerns regarding soil compaction from cattle trampling, subsequent row crop productivity, and economic risks associated with cattle ownership and infrastructure arise. The purpose of this experiment is to thoroughly investigate the impacts of grazing on cover crop and soybean performance.

The objectives of this study are to: 1) evaluate animal performance on three cover crop systems, 2) assess forage mass and nutritive value of the cover crops in each system, 3) observe subsequent soybean yield following grazing, and 4) calculate economic productivity throughout each stage of production.

Experimental Design and Analysis

This experiment was conducted at the Coastal Plain Branch Experiment Station (CPBES) in Newton, MS (32° 20'N, 89° 04' W) from 2019 to 2021. All animals used in this research were cared for under the auspices of Mississippi State University, Institutional Animal Care and Use Protocol IACUC-19-391. The study site consisted of two experimental areas (grazed and un-grazed) that were separated by 0.75 mi. Soils at each site were predominantly Boswell fine sandy loam (fine, mixed, active, thermic Vertic Paleudalfs) and a Prentiss fine sandy loam (coarse-loamy, siliceous, semiactive, thermic Glossic Fragiudults) for the grazed and un-grazed areas, respectively. The grazed area consisted of an 18-ac pasture that was subdivided into nine (2.0 ± 0.1 ac) paddocks in which, prior to this experiment, had been used for warm-season perennial grass grazing trials where no tillage had occurred in over 3-yrs. The un-grazed area consisted of small plots (15' x 30') where tillage treatments (NT and CT) and un-planted controls were applied. Prior to this experiment, wheat and assorted small grain variety trials had been conducted for 5-yrs in a CT system. Within these two experimental areas, comparisons were made across three ICLS systems: 1. grazed, no-till (GNT), 2. un-grazed, no-till (UNT) and 3. un-grazed, conventional till (UCT). Both experimental areas consisted of randomized complete block designs with three replications of each cover crop treatment in the GNT and three replications of each tillage treatment (NT and CT) with three replications of each cover crop and an unplanted control in the UNT and UCT.

Cover Crop Management

In the grazed area, one of three cover crop treatments were randomly applied to each paddock. Cover crop treatments included oats (O), oats + crimson clover (OC), and oats + crimson clover + tillage radish (OCR). Cover crop seeding rates, and cultivars can be found in Table 2.1. Seeding was accomplished using a no-till drill with 7.5-in row spacing (Truax FLX-11-88, Truax Co., New Hope, MN). Following seeding, all paddocks were fertilized with 50 lb N ac^{-1} (O) or 25 lb N ac^{-1} (OC and OCR) using urea ammonium sulfate (33-0-0-12S). In the un-grazed area, cover crops were managed identically to the grazed area with the addition of an unplanted control (CTR) treatment, and tillage treatments. The UCT system consisted of tillage applications made prior to cover crop establishment in the fall of each year. Each event consisted of two passes with a disk harrow to incorporate crop residues, followed by a single pass with a section harrow equipped with rolling baskets for final seed-bed preparation. In the GNT and UNT systems, no-till establishment of the cover crop was used throughout the experiment.

Table 2.1 Cover crop treatments and bulk seeding rates for years 1 and 2 for both grazed and un-grazed experiments established in Newton, MS (2019-2021).

Treatment	**Species**	**Cultivar**	**Seeding rate (lb ac^{-1})**
O	oats	Bob	80
OC	oats + crimson clover	AU Sunrise	80 + 10
OCR	oats + crimson clover + radish	Daikon	80 + 10 + 5

Cover crop data collection included forage mass (FM), and nutrient analysis (CP - crude protein and TDN - total digestible nutrients). In the grazed area, nine subsamples were taken within each paddock at the beginning and end of each 28-d grazing period, and every two weeks throughout the remainder of the grazing season, with a final sample being taken after cattle were removed. In the un-grazed area, subsamples were taken at the same time as the grazed area at two randomly placed areas per plot. All subsamples were clipped from 2-ft^2 areas to a height of 3-in, weighed, placed in a forced-air oven at 140° F for 72-hr, and reweighed to determine percentage moisture and to calculate FM. The samples were then ground (Thomas-Wiley Laboratory Mill, Thomas Scientific) to pass through a 1-mm sieve and were analyzed using near infrared reflectance spectroscopy (NIRS: SpectraStar 2600XTR: UCal Calibration Software v3.0, Millford, MA). Crude protein, acid detergent fiber (ADF), neutral detergent fiber (NDF), fat, lignin, ash, and mineral (Ca, K, Mg, and P) concentrations were determined using the 2018 mixed hay equation (NIRS Forage and Feed Testing Consortium: Berea, KY). For TDN, calculations were determined using the sum of the digestible fiber (dNDF), CP, fat, and carbohydrate components (Saha et al., 2014; NRC, 2016). Prior to soybean establishment, after a burndown herbicide application, cover crop residue samples were taken from both grazed and un-grazed experimental areas.

Cattle Management

In the grazed area (GNT), 36 weaned beef (*Bos taurus*), predominantly Angus crossbred, steers were used to graze cover crop treatments. Average steer weights were 568.19 lb (± 39.2 lb) and 739.72 lb (± 58.4 lb) for 2019-2020 and 2020-2021 grazing seasons, respectively. Steers were preconditioned for 45-d prior to being placed on the trial. This included individual identification (ear tag), anthelmintic treatment (ivermectin), and vaccination (tulathromycin) for bovine respiratory disease. During the receiving period, steers were placed on dormant bermudagrass pasture and fed a mineral supplement [Fall and Winter Beef Mineral (19.3% calcium, 6% phosphorus), Archer Daniels Midland Company (ADM), Decatur, IL] and *ad libitum* bermudagrass hay. To adjust rumen microbial population, all steers were placed on oat pasture 12-d before the trial began. Steers were then ranked by weight, forming two groups consisting of lighter and heavier sets (Burns and Fisher, 2013). Two from the lighter set were paired with two from the heavier set and were randomly assigned to each experimental paddock. This procedure reduced variation in animal weight per paddock and aided in forage management. Due to the challenges of determining the optimum number of animals to place in individual paddocks, and the uncertainty of determining when to initiate and terminate grazing, a set stocking rate of 1,200 lb ac^{-1} for yr 1 and 1,400 lb ac^{-1} for yr 2, or 4-hd per paddock, was used throughout the duration of the trial and no additional animals were added to any paddock (Biermacher et al., 2012).

Grazing commenced once forage canopy heights reached approximately 12 in. All paddocks were grazed continuously, and steers were removed once forage heights fell to approximately 4 in, or when forage quality was estimated to limit animal performance (Bouton and Gates, 2003; Biermacher et al., 2012). When steers were removed, they were placed back on stockpiled oat pasture, and paddocks were allowed to rest until re-stocking levels were met. During each grazing period, steers had *ad libitium* access to mineral, fresh water, and shade. Steers were weighed un-shrunk at the beginning and end of each grazing period.

Steer performance data included animal days (AD), average daily gain (ADG), and total gain per acre (GAIN). Animal days were determined as the sum of the number of days steers remained on each paddock. Average daily gain was calculated by dividing total animal gain by the number of days of grazing for each animal. Total gain per acre was calculated by dividing total weight gain for all four animals per paddock by the actual size of the paddock.

Soybean Management

Prior to soybean establishment in each year, glyphosate [N-(phosphonomethyl)-glycine] at a rate of 1 qt ac^{-1} (2 lb a.i. gal^{-1}) was applied to ensure no regrowth of cover crop and weeds at the time of planting. Potash was applied at a rate of 200 lb K_2O ac^{-1} in the grazed trial and 100 lb K_2O ac^{-1} in the un-grazed trial, based on soil test recommendations from Mississippi State Soil Testing Lab (Mississippi State, MS), prior to planting in yr 1. No other fertilizer was applied to the soybean crop throughout the experimental period. Before planting of the soybean crop, cover crop residue samples were collected as nine subsamples were taken within each GNT paddock, and at two random locations in each UNT plot. Samples were obtained from collecting all above ground biomass from 2-ft^2 areas. Cover crop residues were not taken from UCT as tillage incorporated the residue into the soil profile prior to soybean establishment.

The UCT system consisted of tillage applications made prior to soybean establishment in the spring of each year. Each event consisted of two passes with a disk harrow to incorporate crop residues, followed by a single pass with a section harrow equipped with rolling baskets for final seed-bed preparation. In the GNT and UNT systems, no-till establishment of soybeans was used throughout the experiment. The soybean variety was A4618 maturity group 4.6 (Amp Genetics, Loveland, CO) treated with Revise PBI (Innvictis Crop-Care LLC, Loveland, CO), a fungicide and insecticide seed treatment product [clothianidin: €-1-(2-chloro-1,3-thiazol-5-ylmethyl)-3-methyl-2-nitroguanidine; ethaboxam: (RS)-N-(α-cyano-2-thenyl)-4-ethyl-2-(ethylamino)-1,3-thiazole-5-carboxamide; ipconazole: (1RS,2SR,5RS;1RS,2SR,5SR)-2-(4-chlorobenzyl)-5-isopropyl-1-(1H-1,2,4-triazol1-ylmethyl)cyclopentanol; metalaxyl: methyl N-(methoxyacetyl)-N-2,6-xylyl-DL-alaninate] was used throughout this study with a targeted plant population of 120,000 plants ac^{-1}. Soybeans were planted using a no-till vacuum planter on 30-in row spacings (1750 MaxRmerge Plus VacuMeter; John Deere, Moline, IL). Each row unit was equipped with spike-toothed row cleaners (Martin-Till, Elkton, KY) and wave coulters, along with 20-pt dimple closing wheels (Martin-Till, Elkton, KY) for residue management. Stand counts were measured in all ICLS systems by counting the number of seedlings at the V1 growth stage at nine random locations within each GNT paddock and two random rows within each UNT and UCT plot. Stand counts were taken from 17’5” measurements (1/1000th ac). A pre-emerge application [1.3 pt ac^{-1} of S-metolachlor (7.64 lb a.i. gal^{-1}): 2-chloro-N-(2-ethyl-6-methylphenyl)-N-((1S)-2-methoxy-1-methylethyl)acetamide; 0.3 oz ac^{-1} of cloransulam (0.84 lb a.i. lb^{-1}): methyl 3-chloro-2-(((5-ethoxy-7-fluoro(1,2,4)triazolo(1,5-c)pyrimidin-2-yl)sulfonyl)amino)benzoate; and 1 qt ac^{-1} of glyphosate] was applied prior to or soon after soybean establishment both years. In yr 2 (16 Aug 2021), to control redbanded stink bugs (*Piezodorus guildinii*), a pesticide application was made at the R4 growth stage [5 oz ac^{-1} of methoxyfenozide (2.5 lb a.i. gal^{-1}): benzoic acid, 3-methoxy- 2-methyl-,2-(3,5-dimethylbenzoyl)-2- (1,1-dimethylethyl) hydrazide and spinetoram (0.5 lb a.i. gal^{-1}): a mixture of spinetoram-J and spinetoram-L; 4 oz ac^{-1} bifenthrin (2 lb a.i. gal^{-1}): (2-methyl[1,1-biphenyl]-3-yl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethyl-cyclopropanecarboxylate; and 1 pt 100 gal^{-1} vegetable oil ethoxylates, fatty acids].

Total grain yield was measured by harvesting two 6-row by 30-ft plots within each GNT paddock and by harvesting the entire 6-row plot within each UNT and UCT plot. Seed moisture and test weights were measured by taking subsamples from each plot (Aquamatic 5200 -A, Perten Instruments, INC, Springfield IL) and total bu ac^{-1} was calculated for each plot. Dates for all field activities can be found in Table 2.2. This includes information about planting, harvesting, and grazing during two cover crop and soybean seasons.

Table 2.2 Dates of operation and related information for planting, harvesting, and grazing during the cover crop and soybean growing seasons, conducted in Newton, MS (2019-2021).

Operation	Information	2019-2020	2020-2021
Plant G* cover crop	See Table 2.1	9-10 Oct 2019	14-15 Oct 2020
Plant UG* cover crop	See Table 2.1	17 Oct 2019	15 Oct 2020
Fertilize UG	50 lb N ac^{-1}	12 Dec 2019	9 Nov 2020
Fertilize G	O (50 lb N ac^{-1}) OC and OCR (25 lb N ac^{-1})	3 Feb 2020	12 Nov 2020
Grazing	Start	9 Jan 2020	3 Mar 2021
Forage sampling	Start	9 Jan 2020	3 Mar 2021
Grazing	End	9 Apr 2020	7 Apr 2021
Forage sampling	End	9 Apr 2020	7 Apr 2021
Glyphosate	Burndown (1 qt ac^{-1})	9 Apr 2020	8 Apr 2021
Residue sampling	G + UG	27 Apr 2020	20 Apr 2021
Fertilize G	200 lb/K ac^{-1}	28 Apr 2020	
Fertilize UG	100 lb/K ac^{-1}	28 Apr 2020	
Plant G soybeans		28 Apr 2020	21-22 Apr 2021
Plant UG soybeans		28 Apr 2020	22 Apr 2021
Pre-emerge	S-metolachlor (1.3 pt ac^{-1}) Cloransulam (0.3 oz ac^{-1}) Glyphosate (1 qt ac^{-1})	4 May 2020	14 May 2021
Weed control	Glyphosate (1 qt ac^{-1})	11 Jun 2020	
Insecticide	Methoxyfenozide + Spinetoram (5 oz ac^{-1}) Bifenthrin (4 oz ac^{-1})		16 Aug 2021
Paraquat	Burndown (10 oz ac^{-1})	17 Sep 2020	7 Sep 2021
Harvest UG soybeans		28 Sep 2020	12 Oct 2021
Harvest G soybeans		7 Oct 2020	12 Oct 2021

*G - grazed and UG - un-grazed

Economic Analysis

Expected profitability for each of the three ICLS systems was determined by calculating the expected revenues and costs associated with each production practice for each system. Only the costs that varied between each system were considered for analysis. These costs include fertilizer, seed and seed treatment, establishment, herbicide, insecticide, and custom application rates, and opportunity costs for capital. To determine expected revenue for each grazing system, average GAIN (lb ac^{-1}) for yrs 1 and 2 was multiplied by the expected value of gain (US$ lb^{-1}). The expected value of gain was calculated for cattle in each system as the difference between the end value of cattle (final price multiplied by final weight) and the beginning value of cattle (initial price multiplied by initial weight) divided by the total gain per acre (Biermacher et al., 2012). Expected value of gain ($ lb^{-1}) was determined using Mississippi regional prices from archived stockyard reports. To determine expected revenue for each soybean system 2 yr (2020 and 2021) average yield (bu ac^{-1}) was multiplied by the expected value of soybean (US$ bu^{-1}) based on Mississippi averages from 2020 and 2021. Statewide (Mississippi) average prices were used for all inputs, including fertilizer, herbicide, insecticide, and seed, with an annual percentage rate of 7.5% used to calculate opportunity cost for capital. Custom rates for fertilizer, herbicide and insecticide applications were used from the Mississippi Forage Planning Budget 2021 and the Mississippi Soybean Planning Budget 2020 (Maples et al., 2020; Maples et al., 2019.).

Statistical Analysis

Statistical analysis was conducted using ANOVA in SAS (SAS Institute, 2013). The PROC GLIMMIX procedure was used to determine differences between fixed effects of ICLS systems (GNT, UNT, and UCT), while replication (1, 2, and 3) and year (2019-2020 – year 1; 2020-2021 – year 2) were considered random effects. Forage characteristics (FM, CP, and TDN were compared across all ICLS systems. Animal Performance (AD, ADG, and GAIN) comparisons were made within GNT only. Soybean production (stand counts and grain yield) was compared across all ICLS systems. Mean separations were based on Tukey's protected least significant difference (LSD) and differences were considered significant at 0.05 probability level. Some interactions between main effects were observed, however, these interactions were small in magnitude compared to the larger influences of the main effects. Therefore, the discussion will focus only on main effects.

Results and Discussion

Environmental Conditions

Precipitation (in) and temperature (high and low; °F) were manually recorded throughout this study from a weather station located <1 mi from both grazed and un-grazed experimental areas. Information regarding precipitation and temperature can be found in Figure 2.1 and Figure 2.2, respectively. In yr 1 (2019-2020) rainfall amounts were well above the 70-yr average for the months of Oct, Jan, and Feb. In yr 2 (2020-2021), rainfall amounts for the summer months of Jun, Jul, and Aug greatly exceeded that of the 70-yr average. Both high and low temperatures in the winter of yr 1 (2019-2020) were above the 70-yr average, except for the mean high temperature for the month of Feb. In yr 2 (2020-2021), mean high and low temperatures for Feb were below that of the 70-yr average.

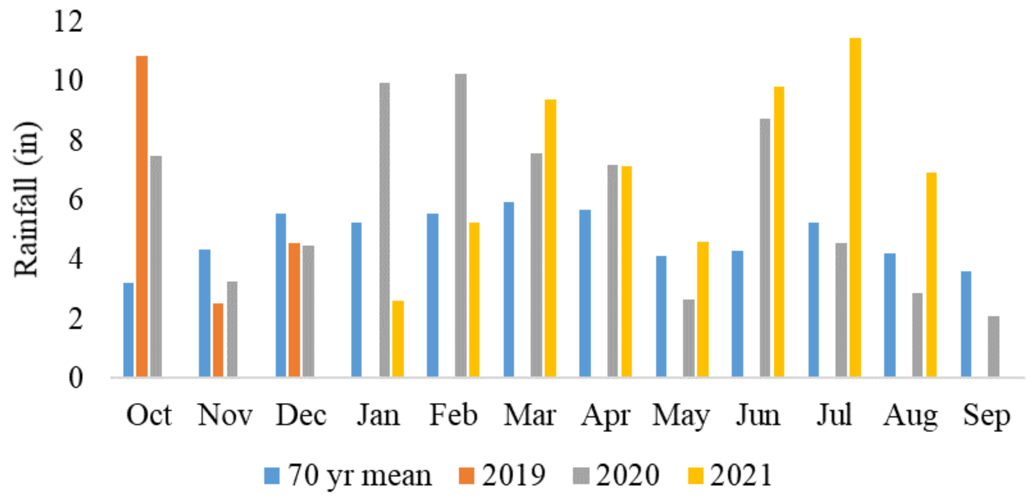

Figure 2.1 Total monthly precipitation (in) with 70-yr historical means for Newton, MS, 2019-2021. Weather data was obtained from daily recordings at the Coastal Plain Branch Experiment Station beginning October 2019.

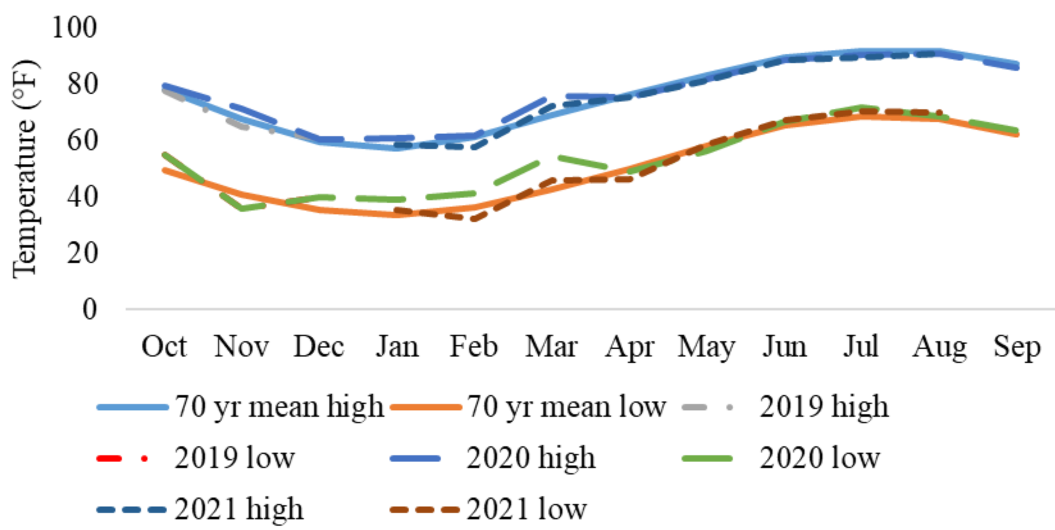

Figure 2.2 Mean monthly high and low temperatures (°F) with 70-yr historical means for Newton, MS, 2019-2021. Weather data was obtained from daily recordings at the Coastal Plain Branch Experiment Station beginning October 2019.

Animal Performance

Year was treated as a random effect and the reported values are least squared means between years 1 and 2 for all data collected throughout the grazing season. The main effect of species for ADG, GAIN, and AD can be found in Table 2.3. The impact of species on ADG was found to be significant (P = 0.03) as it was observed that OCR produced an ADG that was less than O and OC (3.03 vs. 3.52, 3.55 lb hd^{-1} d^{-1}, respectively; Figure 2.3). Beck et al. (2005) observed similar ADG in oats during the spring months (3.50 and 3.21 lb hd^{-1} d^{-1} for yrs 1 and 3, respectively). In a study by Kouka et al. (1994) comparing oats to other small grains, oats produced the greatest ADG. However, results from this research indicated that cattle gained on average 3.52 lb hd^{-1} d^{-1}, much greater than the ADG as recorded by Kouka et al. (1994) of 2.23 lb hd^{-1} d^{-1} with cross-bred heifers. Lowest ADG in OCR could be due in part to visually observed cattle selectivity, as oats and crimson clover were preferred in OCR over radish. Total gain per acre was also affected by species (P = 0.02) as GAIN for OCR (346 lb ac^{-1}) was significantly less than O and OC (430 lb ac^{-1} and 441 lb ac^{-1}, respectively; Figure 2.4). At a stocking rate of 2 hd ac^{-1}, Siri-Prieto et al. (2007) observed a similar GAIN of 483 lb ac^{-1} on oats from Jan - Apr. No significant differences were observed between species for AD ($P \geq 0.05$). Animal grazing days for years 1 and 2 totaled 66 days and 36 days respectively. Initiation of grazing was 9 Jan 2020 and 2 Mar 2021 for yrs 1 and 2 (Table 2.2). Insufficient rainfall in Jan 2021 (2.61 in) and mean low temperatures in Feb 2021 (34°F) influenced available forage, explaining a later initiation of grazing in yr 2.

Table 2.3 Mixed-effects ANOVA model for average daily gain (ADG), total gain per acre (GAIN), and animal grazing days (AD) for 2019-2020 and 2020-2021 grazing seasons, Coastal Plain Branch Experiment Station, Newton, MS.

	ADG		GAIN		AD	
Variable	***F* value**	**Pr > F**	***F* value**	**Pr > F**	***F* value**	**Pr > F**
Species (SPE)	3.65	0.03	5.15	0.0243	0.35	NS*

*NS - not significant.

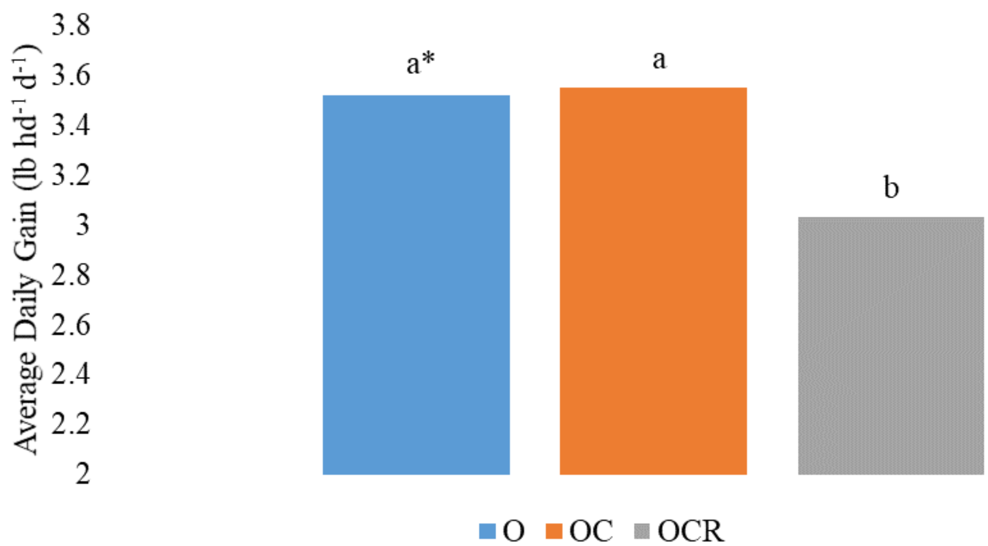

Figure 2.3 Mean average daily gain (lb hd^{-1} d^{-1}) for all grazing events from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS. Treatments include oats (O), oats + crimson clover (OC), oats + crimson clover + radish (OCR).

*Different letters denote a significant difference at the level α=0.05.

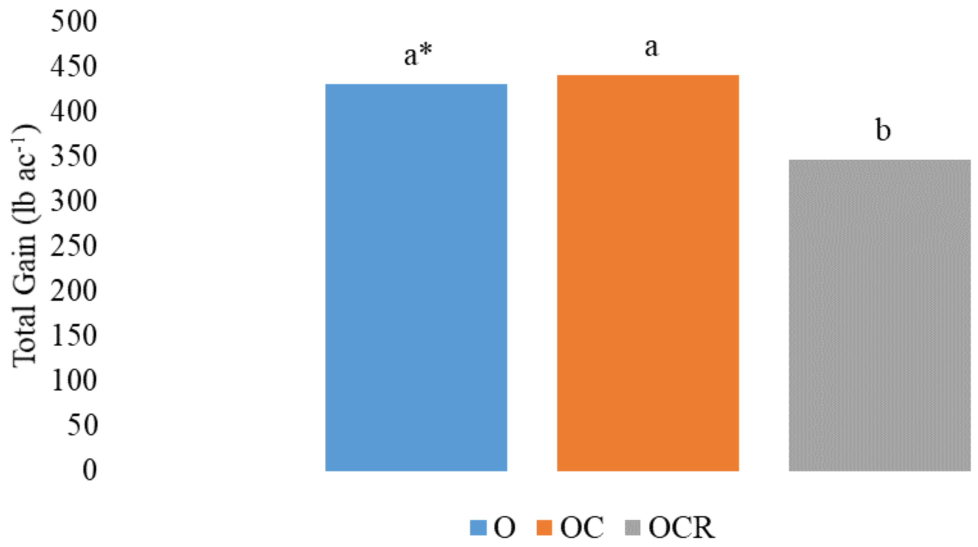

Figure 2.4 Mean total gain per acre (lb ac^{-1}) for all grazing events from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS. Treatments include oats (O), oats + crimson clover (OC), oats + crimson clover + radish (OCR).

*Different letters denote a significant difference at the level α=0.05.

Forage Production and Nutritive Value

The main effects of species, tillage, and date can be found for FM, CP, and TDN in Table 2.4. For the main effects of species and tillage, year was treated as a random effect and values are reported as least squared means across yrs 1 and 2 throughout the entirety of the grazing season. Regarding FM, the impact of species was significant ($P < 0.0001$) as O (3,035 lb DM ac^{-1}) resulted in greater FM than OCR (2,625 lb DM ac^{-1}) and CTR (996 lb DM ac^{-1}). Farney et al. (2018) had similar findings as grass production in cover crop mixtures containing oats had the greatest DM production when compared to wheat, rye, and barley (*Hordeum vulgare*). Treatment OC (2,803 lb DM ac^{-1}) was statistically similar to both O and OCR, and CTR produced the least FM of the four treatments (Table 2.5). While it was expected that the unplanted CTR would produce the least FM, it can be assumed that differences in O and OCR were likely due to extreme weather events in Feb of yr 2, as radish in OCR experienced substantial winter kill (Figure 2.2). The effect of tillage treatments on FM was significant ($P < 0.0001$) as GNT produced significantly less (1,264 lb DM ac^{-1}) than the un-grazed treatments (UNT and UCT; 2,901 and 2,930 lb DM ac^{-1}, respectively; Table 2.5.), due to biomass removal by cattle in GNT. Forage mass was analyzed by date ($P < 0.0001$) for both yrs 1 and 2 for each of the sampling events. Due to biomass accumulation in UNT and UCT, sampling dates of 19 Mar 2020 and 9 Apr 2020 resulted in the greatest FM (5,261 and 4,691 lb DM ac^{-1}, respectively). Initiation of grazing for both yrs (9 Jan 2020, and 2 Mar 2021) produced similar FM (1,292 and 1,029 lb DM ac^{-1}, respectively; Figure 2.5) as grazing did not begin until canopy heights reached 12 in.

Table 2.4 Mixed-effects ANOVA model for forage mass (FM), crude protein (CP), and total digestible nutrients (TDN) for 2019-2020 and 2020-2021 grazing seasons, Coastal Plain Branch Experiment Station, Newton, MS.

	FM		**CP**		**TDN**	
Variable	***F* value**	**Pr > F**	***F* value**	**Pr > F**	***F* value**	**Pr > F**
Species (SPE)	32.92	<0.0001	25.23	<0.0001	20.07	<0.0001
Tillage (TILL)	63.33	<0.0001	19.41	<0.0001	2.41	NS*
DATE	47.98	<0.0001	54.18	<0.0001	16.24	<0.0001
SPE x TILL	7.85	<0.0001	3.10	0.0008	5.72	<0.0001
SPE x DATE	9.23	<0.0001	14.12	<0.0001	9.05	<0.0001
TILL x DATE	27.97	<0.0001	22.14	<0.0001	6.64	<0.0001
SPE x TILL x DATE	21.74	<0.0001	15.22	<0.0001	5.11	<0.0001

*NS - not significant.

Table 2.5 Mean forage mass (FM; lb dry matter ac^{-1}), crude protein (CP; %), and total digestible nutrients (TDN; %) for all sampling events from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS. Species includes oats (O), oats + crimson clover (OC), oats + crimson clover + radish (OCR), and an unplanted control (CTR). Tillage includes grazed no-till (GNT), un-grazed no-till (UCT), and un-grazed conventional till (UCT).

Species	**FM** lb DM ac^{-1}	**CP** % DM	**TDN** % DM
O	3035 a*	14.3 c	58.2 a
OC	2803 ab	15.8 b	58.1 a
OCR	2625 b	15.8 b	57.5 a
CTR	996 c	18.5 a	53.4 b
Tillage			
GNT	1264 b	17.4 a	56.3 a
UNT	2901 a	15.3 b	56.6 a
UCT	2930 a	15.6 b	57.4 a

*Different letters denote a significant difference at the level α=0.05.

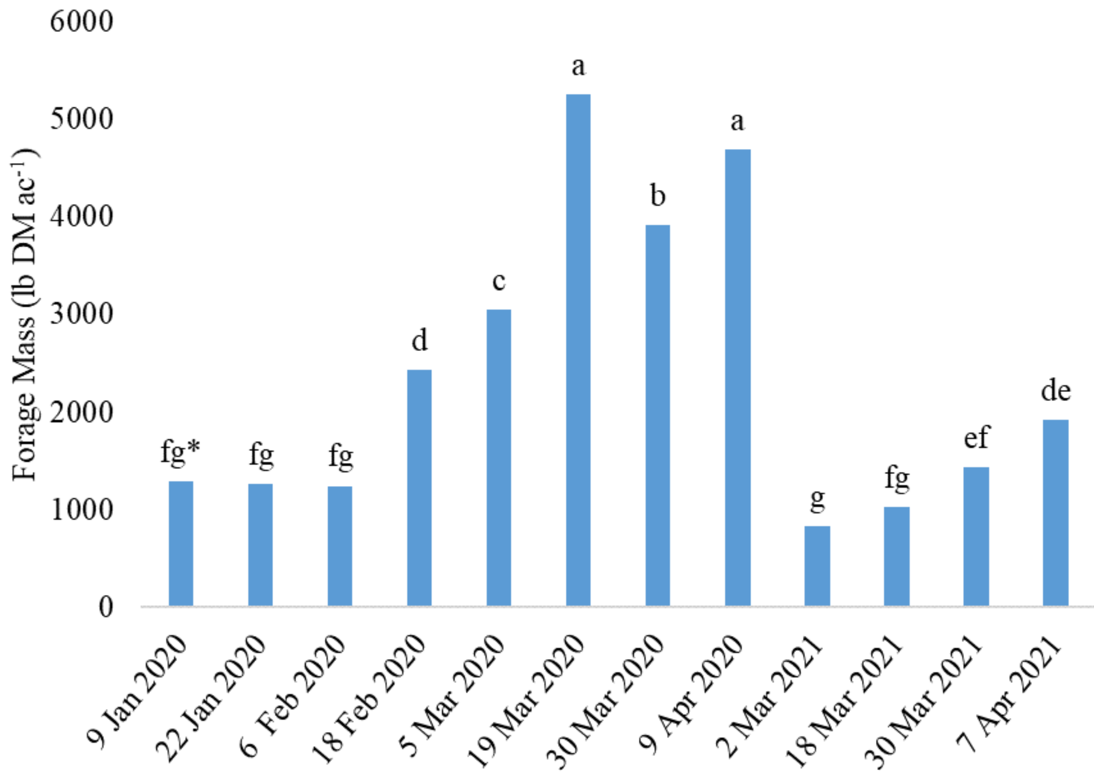

Figure 2.5 Mean forage mass (FM; lb dry matter ac^{-1}) for all sampling events from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS.

*Different letters denote a significant difference at the level α=0.05.

Species significantly affected CP (*P* < 0.0001) as CTR (18.5%) was greater than all other treatments. While CTR was unplanted, volunteer white clover (*Trifolium repens*) was present and caused increased levels of CP. Treatments OCR and OC produced similar CP values of 15.8% and O alone resulted in the lowest mean CP value (14.3%; Table 2.5). This was expected with no legumes present in the treatment. Tillage resulted in a significant difference in CP (*P* < 0.0001) as GNT (17.4%) resulted in the greatest value (Table 2.5). In GNT, the presence of grazing animals impacted forage production in a manner that minimized plant maturation, thus allowing for greater CP concentrations. For CP values regarding date (*P* < 0.0001), which was analyzed for all sampling events in both yrs 1 and 2, the greatest concentration was seen in the first two dates of yr 1 (9 Jan 2020, and 22 Jan 2020; 23.0% and 21.6%, respectively). For both yrs the lowest CP value was observed at the last sampling date [9 Apr 2020 (10.6%) and 7 Apr 2021 (13.5%); Figure 2.6]. Crude protein decreases with plant maturity from late winter into spring, which is consistent with observations from Han et al. (2018).

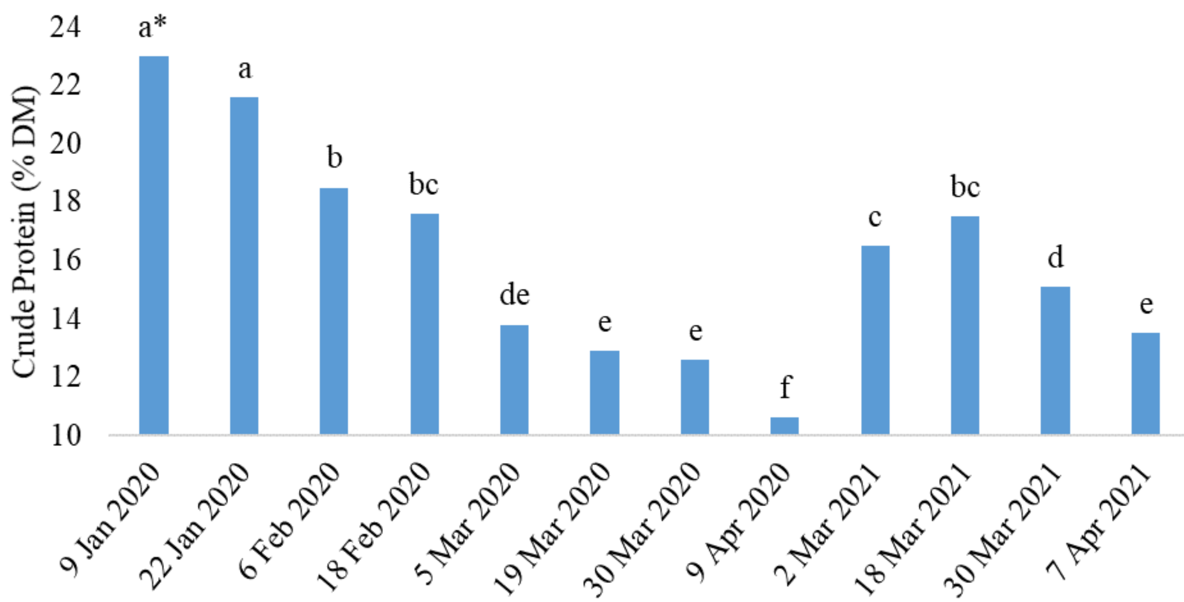

Figure 2.6 Mean crude protein (%) for all sampling events from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS.

*Different letters denote a significant difference at the level α=0.05.

Total digestible nutrients values were significantly affected by species ($P < 0.0001$) as CTR resulted in a TDN concentration of 53.4%. This was significantly less than all other treatments (Table 2.5). With CTR being an unplanted control, less desirable volunteer weed species such as wild mustard (Sinapis arvensis) and henbit deadnettle (Lamium amplexicaule) were present, resulting in a lower TDN than other treatments. Regarding tillage, no significant differences were observed for TDN ($P \geq 0.05$). As mentioned by Farney et al. (2018), timing of sampling plays a role in nutritive value. Date ($P < 0.0001$), analyzed for all sampling events for yrs 1 and 2, was found to be greatest on 9 Jan 2020 and 5 Mar 2020 (61.6% and 60.9%, respectively). Similar to CP, for both years the lowest TDN value was observed at the last sampling date [9 Apr 2020 (52.4%) and 7 Apr 2021 (54.5%); Figure 2.7].

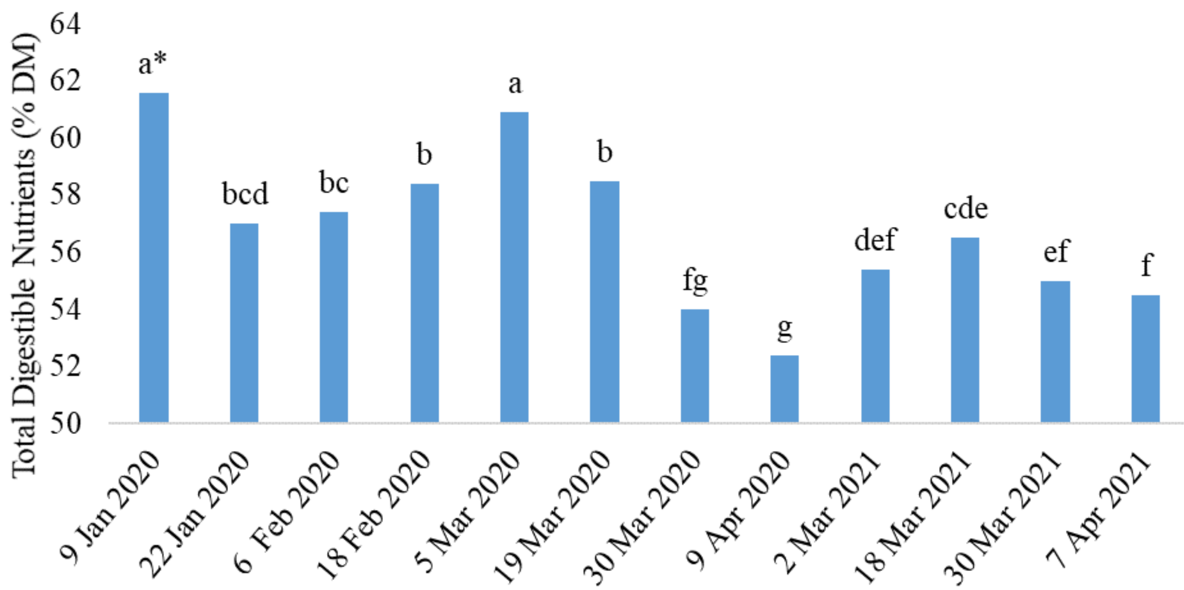

Figure 2.7 Mean total digestible nutrients (%) for all sampling events from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS.

*Different letters denote a significant difference at the level $\alpha=0.05$.

Regarding the relationship of forage nutritive quality to animal performance, a TDN requirement of 68% is needed for a growing steer (1,200 lb finishing wt) to achieve a gain of 2.0 lb d^{-1} (NRC, 2016). As illustrated in Table 2.7, mean TDN values for every sampling date for yrs 1 and 2 were less than the required value of 68%. However, ADG for all three grazed treatments was greater than the previously mentioned 2.0 lb d^{-1}. For a period after purchase (yr 1: Oct 2019

- Jan 2020, yr 2: Oct 2020 - Mar 2021) until the 12-d prior to the start of the trial, cattle were on dormant bermudagrass and were fed bermudagrass hay. It is possible that during this time the net energy requirements for maintenance (NEm) of the steers were lowered, as body condition declined. While TDN provides an estimate for energy, the steers were able to gain at a greater rate than expected according to reported TDN values, due to a lower net energy requirement for gain (NEg), because of their lowered NEm.

Soybean Production

The main effects of species and tillage for soybean yield, stand count, and cover crop residue can be found in Table 2.6. Year was treated as a random effect and all values are least squared means reported between yrs 1 and 2. It should be noted that in UNT and UGT deer (*Odocoileus virginianus*) pressure resulted in yield that was insufficient for data collection in yr 1, therefore comparisons of yield for the effect of tillage cannot be made for yr 1. The effect of tillage was not significant for yr 2 ($P \geq 0.05$). The effect of species ($P \geq 0.05$) on soybean yield was also insignificant. This is inconsistent with the findings of Reddy (2001) as it was observed that a crimson clover cover crop generated greater subsequent soybean yield than an oat cover crop. The impacts of grazing and biomass removal is a potential factor for the difference between this study and the observations of Reddy (2001). While our results for soybean yield regarding the effects of both tillage and species were insignificant, mean yield for species in GNT, UCT, and UNT was recorded as follows: O (38.8 bu ac^{-1}), OC (39.0 bu ac^{-1}), OCR (34.8 bu ac^{-1}), and CTR (31.4 bu ac^{-1}).

Table 2.6 Mixed-effects ANOVA model for soybean yield, stand count, and cover crop residue for 2020 and 2021 soybean growing seasons, Coastal Plain Branch Experiment Station, Newton, MS.

	Yield		**Stand Count**		**Residue**	
Variable	***F* value**	**Pr > F**	***F* value**	**Pr > F**	***F* value**	**Pr > F**
Species (SPE)	0.50	NS*	0.57	NS	5.28	0.0043
Tillage (TILL)	3.05	NS	54.40	<0.0001	49.14	<0.0001
SPE x TILL	1.19	NS	10.70	<0.0001	8.88	<0.0001

*NS - not significant.

Cover crop residue was affected by species ($P = 0.0043$), as CTR produced significantly less biomass than all other treatments (707 lb DM ac^{-1}; Table 2.7) as this treatment was unplanted. Tillage also affected residue ($P < 0.0001$), with UNT (5,887 lb DM ac^{-1}) producing significantly more than GNT (1,187 lb DM ac^{-1}), which can be explained by grazing, as biomass was removed. Residue in UCT was not recorded, as tillage incorporated the residue into the soil profile. Soybean stand count was unaffected by species ($P \geq 0.05$). Differences in tillage treatment for stand count ($P < 0.0001$) were observed as GNT produced a greater mean stand count (104,000 plants ac^{-1}) than the un-grazed treatments (Table 2.7). An increase in stand count for GNT compared to UNT could be explained by higher residue biomass in UNT as soybean seed contact with the soil may have been impeded.

Table 2.7 Mean cover crop residue (lb dry matter ac^{-1}), and soybean stand count (plants ac^{-1}) for 2020 and 2021 growing seasons, Coastal Plain Branch Experiment Station, Newton, MS. Species includes oats (O), oats + crimson clover (OC), oats + crimson clover + radish (OCR) and an unplanted control (CTR). Tillage includes grazed no-till (GNT), un-grazed no-till (UCT), and un-grazed conventional till (UCT).

Species	**Residue** lb DM ac^{-1}	**Stand count** plants ac^{-1}
O	4135 a*	82,000 a
OC	4778 a	80,000 a
OCR	4432 a	81,000 a
CTR	707 b	85,000 a
Tillage		
GNT	1137 b	104,000 a
UNT	5887 a	74,000 b
UCT	--------	68,000 b

*Different letters denote a significant difference at the level α=0.05.

Economics

Costs related to each of the 3 cover cropping systems, value of animal gain, expected revenue of animal gain, expected revenue of soybean yield, expected total revenue, and differences in expected returns from ICLS costs can be found in Table 2.8. All values are least squared means reported for yrs 1 and 2. A significant difference in expected returns was observed as OCR ($749.31 ac^{-1}) generated a significantly lower expected economic return than O and OC ($1,017.04 ac^{-1} and $989.90 ac^{-1}, respectively). Increased total production costs in OCR as well as lower returns from animal gains and soybean yield resulted in expected returns to be significantly less for this system. Franzluebbers and Stuedemann (2007) observed a net return over variable costs of $122 ac^{-1} when a cover crop was grazed by cattle. Differences between this ICLS utilizing a soybean cropping system, and the sorghum and winter wheat cropping systems studied by Franzluebbers and Stuedemann (2007) could explain differences in returns as revenue from crop yield varied between each system.

Table 2.8 Animal and soybean economic analysis for oats (O), oats + crimson clover (OC), and oats + crimson clover + radish (OCR) for year 1 and 2 (2019-2020; 2020-2021) grazing and cropping seasons, Coastal Plain Branch Experiment Station, Newton, MS.

	System		
Economics	**O**	**OC**	**OCR**
Fertilizer and application expenses ($ ac^{-1})	123.57	111.07	111.07
Herbicide and application expenses ($ ac^{-1})	62.36	62.36	62.36
Insecticide and application expenses ($ ac^{-1})	21.03	21.03	21.03
Cover crop seed and establishment expenses ($ ac^{-1})	33.60	44.20	61.30
Soybean seed and establishment expenses ($ ac^{-1})	66.00	66.00	66.00
Interest on annual operating capital ($ ac^{-1})	22.99	22.84	24.13
Total production cost ($ ac^{-1})	329.55	327.50	345.89
Value of animal gain ($ lb^{-1})	2.12	2.11	2.05
Total animal gain (lb ac^{-1})	430.01	441.29	346.38
Expected revenue of animal gains ($ ac^{-1})	799.46	823.43	680.57
Soybean yield (bu ac^{-1})	51.14	46.17	38.75
Expected revenue of soybean yield ($ ac^{-1})	547.13	493.96	414.63
Expected total revenue ($ ac^{-1})	1,346.59	1,317.39	1,095.20
Expected returns from above ICLS costs ($ ac^{-1})	1,017.04 a	989.90 a	749.31 b

The expected returns for this system are based only on the fixed costs outlined in Table 2.8. In an ICLS system there are several costs that would vary depending on operation, which were not included in this economic analysis. Infrastructure costs such as fencing, cattle handling facilities, water troughs, etc., were not calculated. Cattle receiving and maintenance costs related to vaccinations, and supplemental feed prior to grazing cover crops were also not considered. Therefore the overall net returns for each over cropping system were not calculated, only expected returns from the fixed ICLS costs outlined in Table 2.8.

Summary

With the implementation of an ICLS the management considerations related to production are crucial for each component of the system. Regarding the expected profitability of each of the three cover cropping systems, OCR produced a significantly lower expected economic return (\$749.31 ac^{-1}) when compared to O and OC (\$1,017.04 ac^{-1} and \$989.90 ac^{-1}, respectively). Aside from monetary value, there were several significant differences observed throughout various stages of production. Animal performance was found to be less in terms of ADG and GAIN in OCR. While animal performance for all three species was sufficient to sustain growing cattle, O and OC proved to be much more productive. The visual observation of species selection by cattle grazing was evident as oats and crimson clover were preferred over radish. In addition, forage production was also observed to be less in OCR when compared to O, also contributing to lower ADG and GAIN in OCR. This information could have an effect on management considerations in an ICLS for producers selecting cover crop species to provide the greatest forage availability, as well as the capability to generate the greatest animal gains. In addition to forage and animal production in ICLS, soybean cropping has management considerations to be taken into account as well. While yield was unaffected by cover cropping systems, stand count was significantly greater in GNT. This was directly attributed to removal of cover crop residue when compared to un-grazed treatments, proving that grazing cover crops is an effective means of biomass management allowing for optimal soybean seedling emergence. Also, concerns over seed bed formation due to cattle traffic and their impacts on seedling development was negligible. Ultimately, the ICLS studied in this experiment have proved to be successful in terms of providing animals with sufficient forage to generate gain, soybean production, and overall profitability in terms of expected returns when implemented in the

Coastal Plain region of east-central Mississippi. However, future research should be conducted regarding these individual components of ICLS and how production is affected.

Conclusions

In conclusion, several considerations should be made by producers in Mississippi looking to implement this ICLS. If animal gains are of the greatest importance when selecting a cover crop then producers should select O or OC over the three-way mixture OCR. It should be noted that while this ICLS utilized steers for grazing, the opportunity exists to utilize cover crops as an additional source of forage for a cow-calf herd as well, resulting in lowered hay feeding costs for producers. Regarding soybean yield, there should be no concern of a decrease in yield between any of the three cover cropping systems based on the findings of this study. Concerning economic returns, the use of OC or O should be selected over the tree-way mixture OCR. Ultimately, this ICLS will provide producers with an opportunity for greater returns than cover cropping alone.

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CHAPTER III

INTEGRATED CROP-LIVESTOCK SYSTEM EFFECTS ON SOIL CHARACTERISTICS

Impacts of Grazing Cover Crops on Soil Physical and Chemical Properties

Over the past 20 years, there has been a growing interest regarding the topic of soil health, as it is directly related to the sustainable management of agricultural land (Karlen, et al., 1997). Soil health is dependent upon the maintenance of 4 key functions: 1) the maintenance of soil structure, 2) regulation of diseases and pests, 3) cycling of nutrients, and 4) carbon sequestration (Kibblewhite et al., 2008). One agricultural practice implemented to improve or sustain soil health is cover cropping. This practice involves planting a cover crop during the off-season of a row crop production system when a field would otherwise be left fallow. In the southeastern U.S., cover crops are generally annual cool-season species grown in rotation with warm-season row crops. Cover cropping provides many benefits to the soil such as erosion prevention, water infiltration, soil carbon sequestration, etc. Conservation tillage combined with cover cropping allows for increased organic matter content, improved soil aggregate and water infiltration, and increases the efficiency of nutrient cycling (Franzluebbers, 2007).

In a specialized agricultural system known as an integrated crop-livestock system (ICLS) livestock are incorporated into a row crop setting by the means of grazing cover crops. These systems have the same advantages as cover crops/conservation tillage systems, but include additional benefits through livestock grazing, leading to increased economic returns. Aside from the known benefits and opportunities provided by this system, there have been questions regarding the negative impacts on soil properties such as soil compaction and bulk density due to hoof traffic and grazing behaviors.

Soil penetration resistance (PR) and soil bulk density (BD) are physical properties that are frequently evaluated in ICLS research, as they are directly correlated with the structural integrity of the soil as well as the ability to perform the function of nutrient cycling (Kibblewhite et al., 2008). A study by Franzluebbers and Stuedemann (2005) in Watkinsville, GA (Cecil sandy loam soil) evaluated the productivity of two different ICLS in which cover crops were grazed. These researchers concluded that the impacts of grazing on soil properties were variable, as the values of soil penetration tended to be greater in grazed treatments when compared to un-grazed, but it was concluded that this was likely a result of soil water content (SWC) at the time of sampling. Based upon these findings the suggestion was made that without any negative effects to soil health, greater economic returns could be attained by grazing cover crops (Franzluebbers, 2007).

When comparing grazed and un-grazed treatments in an ICLS study (Cecil sandy loam and sandy clay loam soils), Franzluebbers and Stuedemann (2008a.) stated that differences in BD were relatively small as it was found that there was only an increase of 1.08 g cm^{3-1} from 1.02 g cm^{3-1} between grazed and un-grazed treatments, respectively. Soil penetration resistance (PR) was found to be greater in grazed treatments when compared to un-grazed treatments for both conventional tillage (CT) and no-tillage (NT) when averaged across all 10 sampling events [110 J vs. 70 J (CT); and 122 J vs. 109 J (NT), for grazed vs. un-grazed treatments, respectively], at a depth of 0-10 cm. It was stated that because of the large effect at the soil surface, cumulative penetration resistance, to a depth of 30 cm, throughout the soil profile was significantly greater under NT than under CT (Franzluebbers and Stuedemann, 2008a.).

Environmental conditions have shown to influence PR in Cecil sandy loam and Cecil sandy clay loam soils, as excessively wet conditions in the spring months resulted in an increase of PR by 14% (1.95 vs. 1.53 MPa) within 0-30 cm, when comparing grazing a cereal rye (*Secale cereale*) cover crop to rolling (Schomberg et al., 2021). In this study, impacts to the soil surface were still visible the following February (1.86 vs. 1.58 MPa for grazed vs. rolled treatments, respectively), and was concluded that short-term grazing of cover crops during wet conditions posed a risk for adverse soil effects regarding compaction due to hoof traffic in the southern Piedmont of GA (Schomberg et al., 2021). Similarly, Maughan et al. (2009) found PR to be extremely variable (Virden silty clay loam) and attributed this to seasonal conditions that influenced soil water content. Fae et al. (2009) found no differences (Crosby silt loam; Celina silt loam; Kokomo silt clay loam; and Miamian silty clay loam) for PR in May of 2008, but for both May and September of 2007, PR was greatest in oat (*Avena sativa*) + cereal rye (1.45 and 1.61 MPa, respectively) followed by annual ryegrass (*Lolium multiflorum*; 1.36 and 1.43 MPa, respectively) and a no cover crop control treatment (1.27 and 1.37 MPa, respectively for May and Sep 2007).

Soil water content is another soil physical property frequently evaluated in ICLS. Soil water content is often utilized when analyzing PR as seasonal changes could alter SWC and influence PR (Maughan et al., 2009; Schomberg et al., 2021). Clark et al. (2004) found no differences in post-grazing SWC across both grazed and un-grazed paddocks throughout a three-yr study (Marshall silty clay loam; Minden silty clay loam; Corley silt loam; and Colo silty clay). When comparing treatments of grazed vs. rolled cover crops, Schomberg et al. (2021) reported lower SWC at shallower depths (0-15 cm) in grazed treatments as opposed to lower SWC in the rolled treatments at deeper depths (15-30 cm). The drier surface SWC in the grazed treatments was likely due to the biomass removal of the cover crop which did not occur in the rolled treatments (Schomberg et al., 2021). As SWC was related to PR in this study, it was concluded that the differences between treatments in terms of SWC, likely had little if any impact on corresponding PR (Cecil sandy loam and Cecil sandy clay loam soils; Schomberg et al., 2021). Similarly, Franzluebbers and Stuedemann (2008a.) outlined that PR at depths of 0-10 cm was affected very little by SWC in Cecil sandy loam and sandy clay loam soils.

Extensive research on the impacts of grazing crop residues on soil health have been conducted. In a corn (*Zea mays*) - soybean (*Glycine max*) rotational system, BD did not differ between tillage treatments of NT and CT following grazing of corn stubble (Marshall silty clay loam, Minden silty clay loam, Corley silt loam, and Colo silty clay; Clark et al., 2004). Unlike BD, when comparing grazed to un-grazed paddocks there was an increase in PR ($\leq$ 10 cm) during the months of Oct and Nov. Clark et al., (2004) concluded that these soil effects will be minimal regarding subsequent soybean yield if tillage occurs prior to establishment. Unlike the findings of Clark et al. (2004), tillage treatments of CT and NT in a study by Tollner et al. (1990) produced differences in BD due to grazing as it was found that a greater increase in BD occurred in NT treatments (Davidson clay loam).

In addition to soil physical properties, soil organic matter, which is primarily composed of soil organic carbon (SOC), can be utilized in the determination of the health of a soil. Soil organic matter supplies and retains nutrients and water in the soil, improves aggregation, and allows for increased soil microbial activity (Poffenbarger, 2010). In addition to SOC, nitrogen (N), an essential nutrient to plant growth, is an indicator of soil health. The effects of tillage management practices related to soil chemical properties was studied by Franzluebbers and Stuedemann (2008b.). In their study they evaluated impacts of grazing cover crop treatments, and it was found that while CT did result in more uniform SOC distribution compared to NT, both tillage treatments resulted in increased soil microbial carbon biomass during the winter cover cropping period for treatments that included grazing (Cecil sandy loam and sandy clay loam; Franzluebbers and Stuedemann, 2008b.).

Tracy and Zhang (2008) compared the effects of an un-grazed cover crop, grazed cover crop, and perennial cool- and warm-season pastures on changes in SOC content (Virden silty clay loam). Increases in SOC over this four-yr study were found in all three treatments that utilized grazing, where no change was observed in the continuous corn treatment with an un-grazed cover crop. Soil N was found to be increased in the grazed corn + oat cover crop treatment while in the un-grazed cover crop, and perennial pasture treatments, N content remained the same (Tracy and Zhang, 2008). Unlike the findings of Tracy and Zhang (2008), Tobin et al. (2020) reported that for various cover cropping treatments in a corn-soybean rotation system, a change was observed during the corn phase as SOC content was significantly greater in the un-grazed treatments (28.22 and 22.45 g kg^{-1}) than in the grazed (25.64 and 21.17 g kg^{-1}) at 0-5 and 5-10 cm depths, respectively. Regarding SOC as related to cover cropping mixtures it was observed that for a grass blend, containing 76.4% oats, SOC was greater when compared to the legume blend, containing 34.6% pea (*Pisum sativum*; 23.49 g kg^{-1} vs. 21.74 g kg^{-1}). Total N content was greater for the grazed (2.83 g kg^{-1}) than the un-grazed (2.66 g kg^{-1}) treatments in this study (Davidson clay loam; Tobin et al., 2020).

Ultimately, there has been much variation in the literature comparing both soil physical and chemical changes as many factors such as cover crop mixture, grazing intensity, tillage treatment, and weather conditions could all play a factor. The purpose of this experiment is to thoroughly investigate the impacts of grazing cover crops on soil properties. The objectives of this study are to monitor changes in soil physical and chemical properties under ICLS production in east-central Mississippi.

Experimental Design and Analysis

This experiment was conducted at the Coastal Plain Branch Experiment Station (CPBES) in Newton, MS (32° 20’N, 89° 04’ W) from 2019 to 2021. All animals used in this research were cared for under the auspices of Mississippi State University, Institutional Animal Care and Use Protocol IACUC-19-391. The study site consisted of two experimental areas (grazed and un-grazed) that were separated by 0.75 mi. Soils at each site were predominantly Boswell fine sandy loam (fine, mixed, active, thermic Vertic Paleudalfs) and a Prentiss fine sandy loam (coarse-loamy, siliceous, semiactive, thermic Glossic Fragiudults) for the grazed and un-grazed areas, respectively. The grazed area consisted of an 18-ac pasture that was subdivided into nine (2.0 ± 0.1 ac) paddocks in which, prior to this experiment, had been used for warm-season perennial grass grazing trials where no tillage had occurred in over 3-yrs. The un-grazed area consisted of small plots (15’ x 30’) where tillage treatments (NT and CT) were applied. Prior to this experiment, wheat (*Triticum aestivum*) and assorted small grain variety trials had been conducted for 5-yrs in a CT system. Within these two experimental areas, comparisons were made across three ICLS systems: 1. grazed, no-till (GNT), 2. un-grazed, no-till (UNT) and 3. un-grazed, conventional till (UCT). Both experimental areas consisted of randomized complete block designs with three replications of each cover crop treatment in the GNT and three replications of each tillage treatment (NT and CT) with three replications of each cover crop and an unplanted control in the UNT and UCT.

Cover Crop Management

In the grazed area, one of three cover crop treatments were randomly applied to each paddock. Cover crop treatments included oats (O), oats + crimson clover (*Trifolium incarnatum*; OC), and oats + crimson clover + tillage radish (OCT). Cover crop seeding rates and cultivars can be found in Table 3.1. Seeding was accomplished using a no-till drill with 7.5-in row spacing (Truax FLX-11-88, Truax Co., New Hope, MN). Following seeding, all paddocks were fertilized with 50 lb N ac^{-1} (O) or 25 lb N ac^{-1} (OC and OCR) using urea ammonium sulfate (33-0-0-12S). In the un-grazed area, cover crops were managed identically to the grazed area, with the addition of an unplanted control (CTR) treatment, and tillage treatments. The UCT system consisted of tillage applications made prior to cover crop establishment in the fall of each year. Each event consisted of two passes with a disk harrow to incorporate crop residues, followed by a single pass with a section harrow equipped with rolling baskets for final seed-bed preparation. In the GNT and UNT systems, no-till establishment of the cover crop was used throughout the experiment.

Table 3.1 Cover crop treatments and bulk seeding rates for years 1 and 2 for both grazed and un-grazed experiments established in Newton, MS.

Treatment	**Species**	**Cultivar**	**Seeding rate (lb ac^{-1})**
O	oats	Bob	80
OC	oats + crimson clover	AU Sunrise	80 + 10
OCR	oats + crimson clover + radish	Daikon	80 + 10 + 5

Cattle Management

In the grazed area (GNT), 36 weaned beef (*Bos taurus*), predominantly Angus crossbred, steers were used to graze cover crop treatments. Average steer weights were 568.19 lb (± 39.2 lb) and 739.72 lb (± 58.4 lb) for 2019-2020 and 2020-2021 grazing seasons, respectively. Due to the challenges of determining the optimum number of animals to place on individual paddocks, and the uncertainty of determining when to initiate and terminate grazing, a set stocking rate of 1,200 lb ac^{-1}, or 4-hd per paddock, was used throughout the duration of the trial and no additional animals were added to any paddock (Biermacher et al., 2012). Initiation of grazing was 9 Jan 2020 and 2 Mar 2021 and ended on 9 Apr 2020 and 9 Apr 2021 for yrs 1 and 2.

Soybean Management

Prior to soybean establishment in each year, glyphosate [N-(phosphonomethyl)-glycine] at a rate of 1 qt ac^{-1} (2 lb a.i. ac^{-1}) was applied to ensure no regrowth of cover crop and weeds at the time of planting. Potash was applied at a rate of 200 lb K_2O ac^{-1} in the grazed trial and 100 lb K_2O ac^{-1} in the un-grazed trial, based on soil test recommendations from Mississippi State Soil Testing Lab (Mississippi State, MS), prior to planting in yr 1. No other fertilizer was applied to the soybean crop throughout the experimental period. The UCT system consisted of tillage applications made prior to soybean establishment in the spring of each year. Each event consisted of two passes with a disk harrow to incorporate crop residues, followed by a single pass with a section harrow equipped with rolling baskets for final seed-bed preparation. In the GNT and UNT systems, no-till establishment of soybeans was used throughout the experiment. The soybean variety was A4618 maturity group 4.6 (Amp Genetics, Loveland, CO) and the targeted plant population was 120,000 plants ac^{-1}. Soybeans were planted using a no-till vacuum planter on 30-in row spacings (1750 MaxRmerge Plus VacuMeter; John Deere, Moline, IL). Each row unit was equipped with spike-toothed row cleaners (Martin-Till, Elkton, KY) and wave coulters, along with 20-pt dimple closing wheels (Martin-Till, Elkton, KY) for residue management.

Soil Sampling

After initial cover crop establishment in the fall of 2019, volumetric water content (VWC), BD, PR, and soil nutrient analysis parameters were evaluated. These samples were taken bi-annually, after cover crop and soybean establishment in Nov and May of yrs 1 and 2. Nine subsamples were taken within each paddock of the GNT, and at two random locations within each plot in the UNT and UCT. Volumetric water content was recorded using a FieldScout TDR 350 moisture meter (Spectrum Technologies, Aurora, IL) equipped with 8-in probes. Soil BD cores were extracted using an AMS slide-hammer 2” x 2” core sampler (AMS, American Falls ID) to a depth of 6 in. Samples were then placed in a forced-air oven at 140° F for 72-h and a dry weight was recorded. Bulk density in g cm^{3-1} was calculated for each sample. Soil penetration resistance was determined using an impact cone penetrometer (Durham Geo Slope Indicator, Stone Mountain, GA; Herrick and Jones, 2002). A 15-lb slide hammer was dropped 20 in repeatedly on a 1.5 in diameter cone with a 45° point. The amount of times impact was required to reach depths of 10, 20, and 30 cm was recorded, with each strike being equivalent to 2.53 J. Samples analyzed for nutrient analysis were obtained at depths of 0-6 in and 6-12 in using a 12 in soil auger (AMS, American Falls ID). For SOC and N analyzation, one gram of dried, sieved (20-mesh) soil was weighed and analyzed via dry combustion, completed using an organic elemental analyzer (Elementar Vario MAX Cube, Ronkonkoma, NY). Elemental analysis of P, K, Ca, Mg, Na, Zn was conducted in an ICP spectrometer system using the Mississippi Soil Test Method as described by Lancaster (Cox, 2001) in which 5-g of dried, sieved (20-mesh) soil was utilized.

Statistical Analysis

Statistical analysis was conducted using ANOVA in SAS (SAS Institute, 2013). The PROC GLIMMIX procedure was used to determine differences between fixed effects of ICLS systems (GNT, UNT, and UCT), while replication (1, 2, and 3) and year (2019-2020 – yr 1; 2020-2021 – yr 2) were considered random effects. Soil physical characteristics (BD, PR, and VWC) were compared across all ICLS systems. Soil nutrient analysis (SOC, N, P, and K) was compared across all ICLS systems. Mean separations were based on Tukey’s protected least significant difference (LSD) and differences were considered significant at 0.05 probability level. Some interactions between main effects were observed, however, these interactions were small in magnitude compared to the larger influences of the main effects. Therefore, the discussion will focus only on main effects.

Results and Discussion

Environmental Conditions

Precipitation (in) and temperature (high and low; °F) were manually recorded throughout this study from a weather station located <1 mi from both grazed and un-grazed experimental areas. Information regarding precipitation and temperature can be found in Figure 3.1 and Figure 3.2, respectively. In yr 1 (2019-2020) rainfall amounts were well above the 70-yr average for the months of Oct, Jan, and Feb. In yr 2 (2020-2021), rainfall amounts for the summer months of Jun, Jul, and Aug greatly exceeded that of the 70-yr average. Both high and low temperatures in the winter of yr 1 (2019-2020) were above the 70-yr average, except for the mean high temperature for the month of Feb. In yr 2 (2020-2021) mean high and low temperatures for Feb were below that of the 70-yr average.

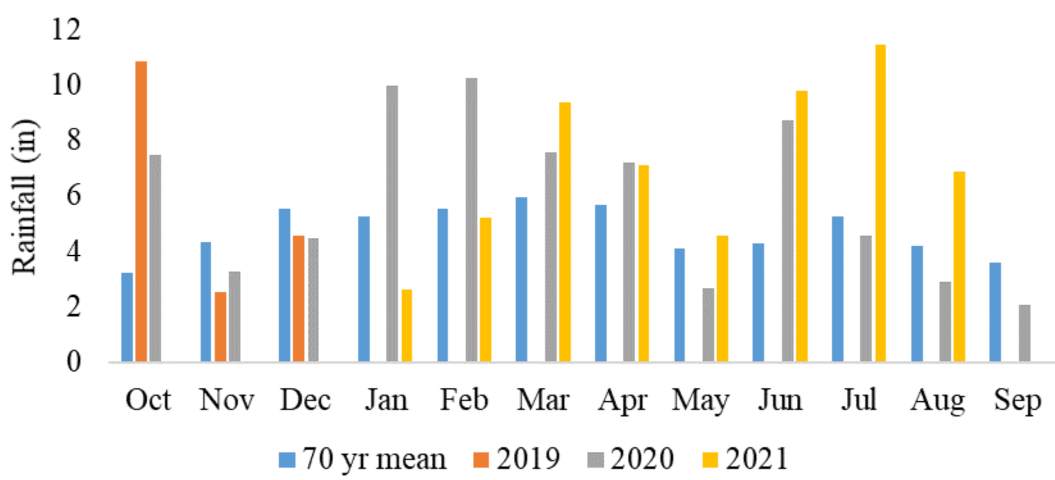

Figure 3.1 Total monthly precipitation (in) with 70-yr historical means for Newton, MS, 2019-2021. Weather data was obtained from daily recordings at the Coastal Plain Branch Experiment Station.

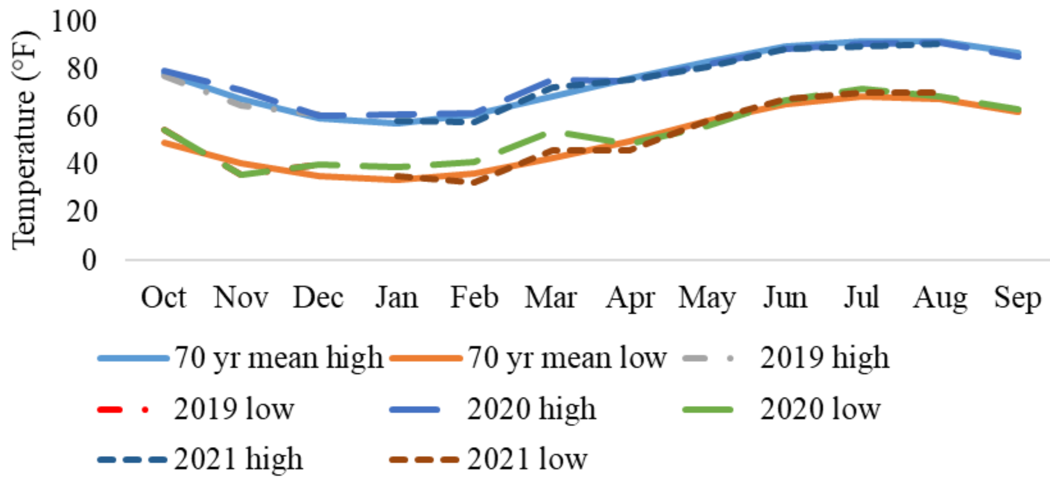

Figure 3.2 Mean monthly high and low temperatures (°F) with 70-yr historical means for Newton, MS, 2019-2021. Weather data was obtained from daily recordings at the Coastal Plain Branch Experiment Station.

Soil Physical Properties

The main effects of species, tillage, and depth can be found for PR in Table 3.2. Year was treated as a random effect with values reported as means across all 4 sampling dates. Species (*P* = 0.0007) impacted PR significantly as OC (44.2 J) was less than all other treatments (Figure 3.3). Fae et al. (2009) reported that a treatment of no cover crop, like CTR in this study, produced less PR than a treatment containing oats. This observation by Fae et al. (2009) is inconsistent with our results as PR for CTR was not significantly different than O and OCR. Tillage ($P \geq 0.05$) was observed to have no effect on PR. This includes the comparison between GNT and UNT, thus illustrating that grazing did not impact PR. Unlike our study, Franzluebbers and Stuedemann (2008a.) observed PR to be greater in grazed treatments when compared to un-grazed treatments for both CT and NT. Clark et al. (2004) observed an increase in PR (≤ 10 cm) in grazed treatments during the months of Oct and Nov, also differing from the results of this experiment. It was found that with an increase in depth (*P* < 0.0001), PR increased accordingly with a depth of 30 cm (74.4 J) having the greatest PR and 10 cm (21.4 J) having the least (Figure 3.4). These findings are similar to those reported by Franzluebbers and Stuedemann (2008a.) as a depth of 30 cm produced the greatest cumulative PR.

Table 3.2 Mixed-effects ANOVA model for soil penetration resistance (PR) Coastal Plain Branch Experiment Station, Newton, MS.

	PR	
Variable	***F* value**	**Pr > F**
Species (SPE)	5.84	0.0007
Tillage (TILL)	0.01	NS*
DEPTH	605.90	<0.0001
SPE x TILL	0.64	NS
SPE x DEPTH	113.59	<0.0001
TILL x DEPTH	145.71	<0.0001
SPE x TILL x DEPTH	39.08	<0.0001

*NS - not significant.

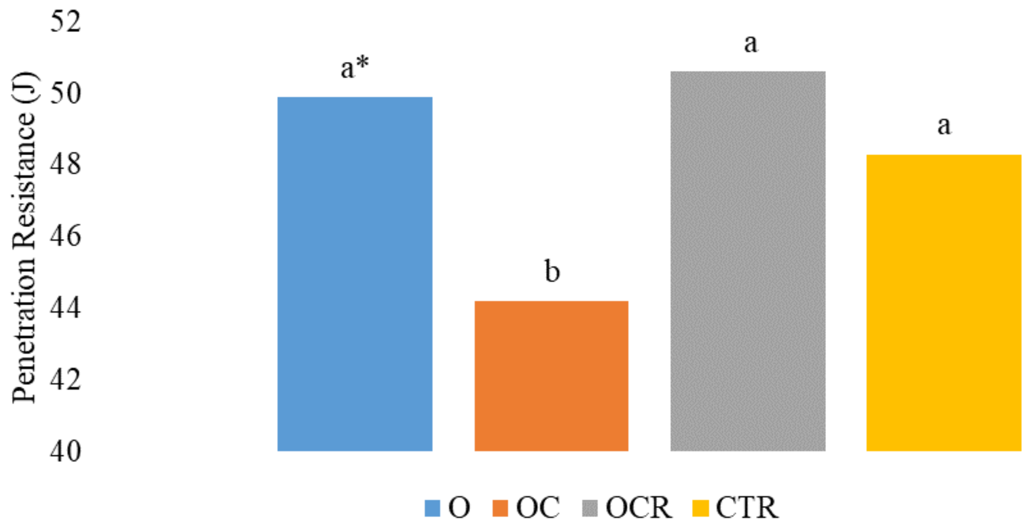

Figure 3.3 Mean soil penetration resistance (J), for all four sampling events, at all depths, for all tillage treatments from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS. Treatments include oats (O), oats + crimson clover (OC), oats + crimson clover + radish (OCR) and an unplanted control (CTR).

*Different letters denote a significant difference at the level α=0.05.

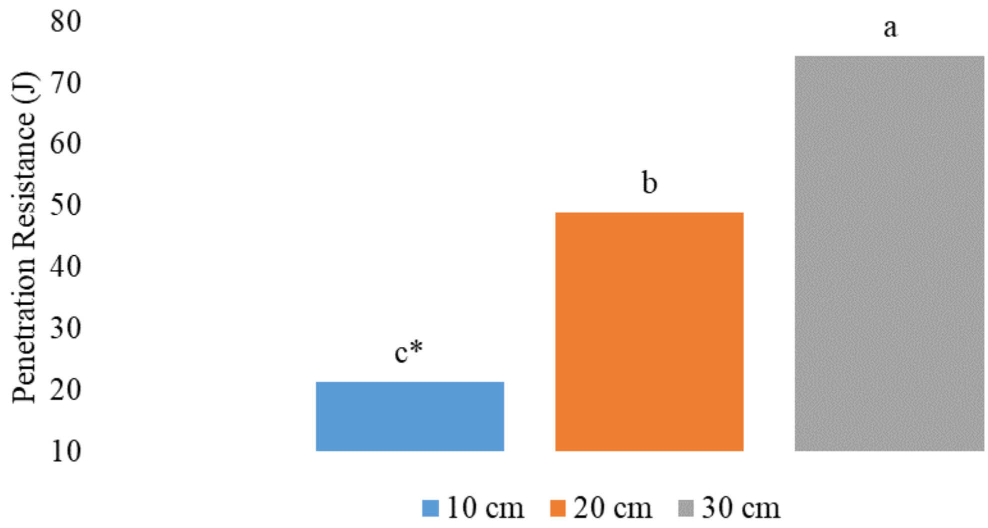

Figure 3.4 Mean soil penetration resistance (J), for all four sampling events, for all tillage and species treatments from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS. Treatments include sampling depths of 10 cm, 20 cm, and 30 cm.

*Different letters denote a significant difference at the level α=0.05.

For BD and VWC, the main effects of species, tillage, and date can be found in Table 3.3. Year was analyzed as a random effect for species and tillage. The main effect of date was analyzed independent of year, with each of the four sampling dates, two from each year, being analyzed separately. Regarding species, both BD and VWC ($P \geq 0.05$) were unaffected by this effect alone. Tillage had a significant impact on BD ($P \geq 0.0001$) as GNT (1.37 g cm^{3-1}) was less than UNT and UCT (1.58 and 1.59 g cm^{3-1}, respectively; Table 3.4). Clark et al. (2004) reported no differences in BD between grazed and un-grazed paddocks, showing variation between studies regarding BD and grazing. An increase in VWC in GNT likely contributed to the differences in BD observed between GNT and UNT (Table 3.4). Date ($P < 0.0001$) affected BD as May and Nov (1.59 and 1.56 g cm^{3-1}) of 2020 resulted in the greatest BD followed by May 2021 (1.50 g cm^{3-1}), with Nov 2019 having the lowest (1.41 g cm^{3-1}; Table 3.4). Variation in seasonal conditions have been stated to cause differences in soil characteristics (Schomberg et al., 2021; Maughan et al., 2009), likely causing differences in BD between sampling dates. Volumetric water content ($P \geq 0.0001$) was also significantly affected by tillage as GNT had the greatest VWC (30.6%), followed by UNT (21.2%), with UCT having the lowest VWC (18.6%; Table 3.4). Clark et al. (2004) observed no differences in mean BD between grazed and un-grazed paddocks post-grazing. In our experiment, it was concluded that the presence of grazing resulted in a difference between GNT and UNT. Date ($P < 0.0001$) affected VWC as Nov 2019 (28.7%) was greater than all other treatments and May 2021 (22.9%) was the lowest of all treatments. Sampling dates of May 2020 and Nov 2020 had statistically similar values for VWC (22.9% and 19.3%, respectively; Table 3.4), once again illustrating the environmental impacts that seasonal weather patterns can have on soil physical properties. Regarding rainfall, for the greatest value of VWC, taken in early Nov 2019, rainfall was well above the 70-yr mean for the month of Oct (10.84 in).

Table 3.3 Mixed-effects ANOVA model for bulk density (BD) and volumetric water content (VWC) for all four sampling events from 2019-2021 , Coastal Plain Branch Experiment Station, Newton, MS.

	BD		VWC	
Variable	***F* value**	**Pr > F**	**F value**	**Pr > F**
Species (SPE)	1.47	NS*	2.54	NS
Tillage (TILL)	63.69	<0.0001	128.17	<0.0001
DATE	23.67	<0.0001	26.24	<0.0001
SPE x TILL	9.95	<0.0001	17.30	<0.0001
SPE x DATE	3.02	0.0004	3.13	0.0003
TILL x DATE	19.64	<0.0001	39.12	<0.0001
SPE x TILL x DATE	6.02	<0.0001	9.49	<0.0001

*NS - not significant.

Table 3.4 Mean bulk density (BD; g cm^{3-1}) and volumetric water content (VWC; %) for all four sampling events from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS. Species includes oats (O), oats + crimson clover (OC), oats + crimson clover + radish (OCR) and an unplanted control (CTR). Tillage includes grazed no-till (GNT), un-grazed no-till (UCT), and un-grazed conventional till (UCT).

Tillage	**BD** g cm^{3-1}	**VWC** %
GNT	1.37 b*	30.6 a
UNT	1.58 a	21.2 b
UCT	1.59 a	18.6 c
DATE		
Nov 2019	1.41 c	28.7 a
May 2020	1.59 a	22.9 b
Nov 2020	1.56 a	19.3 c
May 2021	1.50 b	22.9 b

*Different letters denote a significant difference at the level α=0.05.

Soil Chemical Properties

For the parameters of SOC, N, P, and K, the main effects for species, tillage, and depth can be found in Table 3.5. Year was treated as a random effect and values reported are least squared means averaged across both years of the study. For SOC values, species did not affect concentrations ($P \geq 0.05$). Tillage ($P < 0.0001$) affected SOC with concentrations ranking from greatest to least as follows: GNT (1.44%), UNT (0.66%), and UCT (0.58%; Table 3.6). These results are consistent with that of Franzluebbers and Stuedemann, (2008b.) in which an increase in SOC was observed in paddocks that were grazed compared to those that were un-grazed. Soil organic content was significantly greater at a depth ($P < 0.0001$) of 0-6 in (1.1%) than at 6-12 in (0.7%; Table 3.6). This was expected since SOC typically decreases as soil depth increases.

Table 3.5 Mean soil organic content (SOC; %), nitrogen (N; %), Phosphorus (P; ppm), and Potassium (K; ppm) for all four sampling events from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS. Species includes oats (O), oats + crimson clover (OC), oats + crimson clover + radish (OCR) and an unplanted control (CTR). Tillage includes grazed no-till (GNT), un-grazed no-till (UCT), and un-grazed conventional till (UCT). Depth includes 0-6 in and 6-12 in.

	SOC		**N**		**P**		**K**	
Variable	***F* value**	**Pr > F**	***F* value**	**Pr > F**	***F* value**	**Pr > F**	***F* value**	**Pr > F**
Species (SPE)	1.95	NS*	0.87	NS	4.05	0.0078	4.41	0.0048
Tillage (TILL)	272.18	<0.0001	18.84	<0.0001	142.71	<0.0001	11.87	<0.0001
DEPTH	130.07	<0.0001	6.52	0.0113	19.24	<0.0001	34.47	<0.0001
SPE x TILL	42.04	<0.0001	4.05	<0.0001	35.64	<0.0001	4.48	<0.0001
SPE x DEPTH	8.25	<0.0001	1.36	NS	3.82	0.0006	6.80	<0.0001
TILL x DEPTH	195.78	<0.0001	8.44	<0.0001	69.24	<0.0001	12.48	<0.0001
SPE x TILL x DEPTH	52.40	<0.0001	2.68	0.0002	21.38	<0.0001	5.19	<0.0001

*NS - not significant.

Table 3.6 Mean soil organic content (SOC; %), nitrogen (N; %), Phosphorus (P; ppm), and Potassium (K; ppm) for all four sampling events from 2019-2021, Coastal Plain Branch Experiment Station, Newton, MS. Species includes oats (O), oats + crimson clover (OC), oats + crimson clover + radish (OCR) and an unplanted control (CTR). Tillage includes grazed no-till (GNT), un-grazed no-till (UCT), and un-grazed conventional till (UCT). Depth includes 0-6 in and 6-12 in.

	SOC	**N**	**P**	**K**
Species	%	%	ppm	ppm
O	0.95 a*	0.14 a	158 a	122 a
OC	0.86 a	0.15 a	124 b	108 c
OCR	0.87 a	0.13 a	128 b	113 bc
CTR	0.89 a	0.16 a	137 ab	118 ab
Tillage				
GNT	1.44 a	0.20 a	244 a	124 a
UNT	0.66 b	0.11 b	88 b	117 a
UCT	0.58 c	0.13 b	79 b	105 b
Depth				
0-6 in	1.1 a	0.16 a	153 a	124 a
6-12 in	0.7 b	0.13 b	120 b	106 b

*Different letters denote a significant difference at the level α=0.05.

Nitrogen concentration was unaffected by species ($P \geq 0.05$), while it was found that tillage ($P < 0.0001$) affected N, causing a greater concentration in GNT (0.2%) than UNT and UCT (1.1 and 1.3%, respectively; Table 3.6). Our data is similar to the observations of Tracy and Zhang (2008) in which N content increased in treatments that included cover crops and grazing compared to those that were un-grazed. Depth also significantly impacted N, as it was observed that at a depth of 0-6 in N was greater than at 6-12 in (0.16% vs 0.13%, respectively; Table 3.6). This was expected as N accumulation is greater closer to the soil surface as explained by the process of stratification (Lupwayi et al., 2006).

Species affected phosphorus ($P = 0.0078$) as samples taken within O (158 ppm) had a greater concentration than OC and OCR (124 and 128 ppm, respectively; Table 3.6). Clovers and brassicas generate more P removal via plant uptake resulting in lower concentrations in the treatments containing these species. Harvesting of cover crops like radish can increase the amount of P removed from the soil each year (White and Weil, 2011). Regarding tillage ($P < 0.0001$), GNT (244 ppm) had a greater P concentration than UNT and UCT (88 and 79 ppm, respectively; Table 3.6). Depth also impacted P ($P < 0.0001$), as 0-6 in had a greater concentration than 6-12 in (153 vs. 120 ppm; Table 3.6). This was expected due to higher concentrations of soil nutrients typically occurring closer to the soil surface, which is consistent with the results of Cade-Menun et al. (2010) in which the greatest P concentration was found at the 0-2 in sampling depth.

Potassium levels were affected by species as samples taken from O (122 ppm) were significantly greater than both OCR and OC (113 and 108 ppm, respectively). Treatment OC was found to be significantly less than both CTR (118 ppm) and O (Table 3.6). This was due to the lower rate of potassium removal by O and the volunteer species [white clover (*Trifolium repens),* wild mustard (*Sinapis arvensis*) and henbit deadnettle (*Lamium amplexicaule*)] in CTR. Tillage affected P ($P < 0.0001$) as UCT (105 ppm) was significantly less than treatments of GNT (124 ppm) and UNT (117 ppm) as found in Table 3.6. No-tillage management can increase the nutrient supply of the soil by changing the mineralization process of soil nutrients, such as K, that would occur more readily under CT (Carter and Rennie, 1982). Regarding the effects of depth on P ($P < 0.0001$), concentrations found in samples taken at 0-6 in (124 ppm) were significantly greater than that of samples taken at 6-12 in (106 ppm; Table 3.6). Concentrations of K are greater closer to the soil surface (Lupwayi et al., 2006).

Summary

The potential negative effects that grazing animals could have regarding soil properties has been in question when discussing the impacts of ICLS. Thus, much research has been conducted on the impacts that ICLS have on both soil physical and chemical characteristics. Our research, as it pertains to soil, produced several inconsistencies with other ICLS experiments found in literature. Penetration resistance proved to be less in OC than all other treatments, differing from the results of Fae et al. (2009) in which an unplanted control produced less PR. Also, we observed no difference in PR between grazed and un-grazed areas. This contradicts observations from Franzluebbers and Stuedemann (2008a.) in which PR increased with grazing on sandy loam and sandy clay loam soils. Volumetric water content was found to be greatest in GNT, in which a direct relationship was observed with BD being lowest in GNT, proving that cattle hoof traffic at our stocking rates did not increase BD. It should be noted that environmental conditions at the time of sampling could impact results related to soil physical properties. The results of this study pertaining to soil chemical properties were much more consistent with outside literature as greatest concentrations of SOC as well as N were observed in the GNT treatments. This evidence illustrates that with the presence of grazing animals, nutrient accumulation in terms of SOC and N occurs at a greater rate than when cover crops are un-grazed. Ultimately, considering the inconsistencies with other literature, more research regarding the impacts that grazing animals have in ICLS on soil properties, particularly physical properties, should be conducted.

Conclusions

For producers in Mississippi looking to implement this ICLS, there should be no concerns of negative impacts related to cattle grazing. The findings of this study indicated that both BD and PR were not negatively affected by the presence of grazing animals, illustrating that the presence of cattle grazing cover crops, at our stocking rate, does not negatively affect soil physical properties. Regarding soil chemical properties, producers can expect an increase in both SOC and soil N when grazing cover crops, thus increasing the nutrient supply of the soil by utilizing this ICLS. Ultimately, with no negative impacts on soil health, greater economic returns can be expected by implementing this system.

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