The Pennsylvania State University

The Graduate School

MANAGEMENT INTENSIVE GRAZING OF COVER CROPS FOR SOIL HEALTH AND PROFITABILITY

A Thesis in

Agronomy

by

Divya Pant

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

May 2022

The thesis of Divya Pant was reviewed and approved by the following:

Sjoerd Willem Duiker
Professor of Soil Management and Applied Soil
Thesis Advisor

Ray B. Bryant
Research Soil Scientist
USDA-ARS-Pasture System and Watershed Management Research Unit

Charles M. White
Assistant Professor and Extension Specialist, Soil fertility and Nutrient Management

Erin L. Connolly
Department Head and Professor, Plant Science

ABSTRACT

Management intensive grazing of cover crops (MIGCC) in continuous no-tillage systems is an opportunity to procure mutual benefits of cover crops for improving soil health and providing forage to livestock. However, soil compaction by grazing animals could also have negative effects on soil structure. Therefore, the research studied impact of management intensive grazing of cover crops on soil physical and biological properties as well as forage production and economic returns. The research was conducted on four farms in southcentral Pennsylvania between 2019 and 2021. The comparison was between the grazed and ungrazed cover crop after small grain or corn silage harvest and between double-cropped soybeans and grazed cover crop after small grain harvest. After small grain or corn silage harvest, cover crops were planted and grazed, and cattle were moved daily with a target of leaving roughly 50% of cover crop biomass for soil protection and soil health management.

The first experiment used a randomized full block design with a factorial arrangement of grazing treatment (ungrazed, recently grazed, and grazed 2 weeks earlier) and season (spring or fall) with four farms representing four replication per treatment. Bulk density, aggregate stability, field saturated hydraulic conductivity, soil CO_2 burst, organic matter content, and permanganate oxidizable carbon were not significantly impacted by grazing in spring or fall. In the fall, cover crop grazing produced 1916-3746 kg ha^{-1} forage dry matter, and in the spring, 1425-4349 kg ha^{-1} forage dry matter. Farmers managed to leave an average of 1534-6717 kg ha^{-1} of total cover crop biomass (ranging from 47-73 percent) for soil function and protection. In spring 2020/2021, net revenue from grazing cover crops varied from \$82 ha^{-1} to \$566 ha^{-1}, and in fall 2019/2020/2021, net revenue ranged from \$481 ha^{-1} to \$359 ha^{-1}.

In the second experiment, the impacts of grazed cover crops and soybeans on soil health and economic returns were compared using a completely randomized design with a factorial arrangement of treatments (grazed cover crop versus soybean) and years (2019, 2020, and 2021) on two farms, Franklin 1 and Adams 1. For Franklin 1, findings indicated greater field saturated hydraulic conductivity and soil organic matter content in grazed cover crop field than full-season soybean in

2019 and double-cropped soybean in 2021, while no effect was revealed on soil CO_2 burst. In 2019, full-season soybeans (94%) outperformed grazed cover crops (85%) in terms of aggregate stability, with no difference between treatments in 2020 and 2021. In 2021, the bulk density of the grazed cover crop was lower than in 2020 and 2019. Similarly, the bulk density of soybean fields in 2021 was lower than in 2019. At Adams 1, when compared to double crop soybean, soil under grazed cover crops had higher permanganate oxidizable carbon in 2021 and enhanced structural stability in 2020 and 2021. Between treatments in 2020 and 2021, no significant differences in bulk density, field saturated hydraulic conductivity, soil CO2 burst, or organic matter content were observed at Adams 1.

In 2020 and 2021, partial budget analysis revealed a net positive return of \$523.13 ha^{-1} and \$103.38 ha^{-1} for Adams 1. In 2020 and 2021, however, Franklin 1 had a net return of -\$250.40 ha^{-1} and -\$93.28 ha^{-1}. For Adams 1, a complete soybean failure rendered management intense grazing of cover crops more profitable than a double crop soybean. Double crop soybean failure is common on droughty soils or during years with extreme weather like drought or early frost, making grazed cover crops a less risky alternative to double crop soybeans after small grain harvest. The results so far indicate that grazed cover crop results in better soil health and provides farmers a reduced risk compared with double crop soybean, especially on marginal soils.

The research suggests that under continuous no-tillage systems, grazing cover crops using management intensive practices can provide additional feed and income to the farmer without detrimental effect on soil health, thereby increasing the motivation to adopt cover crops and their derived conservation benefits.

Keywords: Management intensive grazing, soil health, cover crop, corn silage, wheat

Table of Contents

LIST OF TABLES

ACKNOWLEDGEMENT

I would like to express my profound gratitude towards my principal adviser Dr. Sjoerd Duiker. I would like to thank him for providing the opportunity to pursue an MS degree and for his encouragement, incredible support, time, guidance, motivation, and patience throughout these years. Sjoerd hs been a true friend and an amazing mentor, which has helped me grow both personally and professionally. My thanks expand to my advisory committee members, Dr. Ray Bryant and Dr. Charlie White for their continuous guidance and constructive feedback and suggestions throughout my master's program. Many thanks to all the farmers, ARS and RC & D staff, NRCS grazing experts, Penn state extension faculties for their coordination to make this project successful.

My accomplishments are all dedicated to my parents, Shanti Devi Pant and Shiv Raj Pant, and my siblings, Tulsi, Santosh, and Lilu. Their unconditional love, moral support, care, love, and blessings have brought me so far. Thank you to all my friends at Penn State for sharing a co-learning environment, cultural diversity, moments of happiness, and laughter. Special thanks to Moise, Sadikshya, Ryan, Kabita, and Neelam for adding more joy, color, and smile along the journey of graduate education and for being with me through thick and thin. I believe my faith in God has enlightened me in any moments of distress and helped me overcome them.

This work was supported in collaboration of Capital RC&D, Penn State University, and USDA-NRCS with funding from the National Fish and Wildlife Foundation. This work is also supported by the USDA National Institute of Food and Agriculture, Hatch project PEN4764, Accession No 1025969. The findings and conclusions do not necessarily reflect the view of the funding agency.

CHAPTER 1. REVIEW OF LITERATURE AND RESEARCH OBJECTIVES

1.1 Introduction to Cover Crops

Cover crops are grown during fallow periods between commercial crops primarily for soil protection, seedling protection, and improvement of soil health rather than crop production (Sharma et al., 2018). Using cover crops during fallow periods in crop rotations aids in the holistic expression of soil health, which includes the physical, chemical, and biological aspects of the soil (Guo, 2021). Cover crops can be used as mulch by leaving the killed cover crop on the soil surface or can be incorporated into the soil, becoming green manure. Cover crops are considered essential to improve the sustainability of our farming practices because of their multidimensional roles in cropping systems.

Corn grown for silage is a common crop for dairy farmers in the Northeastern U.S. After corn silage harvest around mid-September the soil is nearly barren and planting a cover crop for soil protection becomes especially important (Krueger et al., 2011) and also practical to establish before the onset of winter. Cover crops after corn silage help to buffer against the negative impacts of soil compaction in surface and subsurface soil due to the large machinery and heavy loads being hauled from the fields. This effect of soil compaction from heavy traffic can be alleviated by cover crops because their root systems can combat shallow or deep-seated compaction (Sharma et al., 2018). The roots of the cover crops form a matt-like structure underneath the soil that stabilizes the root zone and the soil surface (White et al., 2020). Cover crop roots and tops protect the soil from the beating action of the rain and scouring of runoff and erosive force of the wind, reducing the risk of wind and water erosion (Obour et al., 2021). Cover crop surface residue reduces runoff velocity, thus reducing the potential for nutrient and soil loss (Adetunji et al., 2020).

Under cropping systems with corn silage, cover crops can be used to protect soil from erosion, provide food for beneficial soil organisms, alleviate compaction, manage soil moisture, and for supplemental weed control (Blanco-Canqui et al., 2015). From the above and below-ground plant biomass, cover crops add organic matter to the soil that provides food for beneficial soil organisms and improves soil structural stability, water holding capacity, and infiltration. The decaying residue supplies essential nutrients for subsequent crops planted after cover crops (A. Clark, 2007). Corn silage fields typically receive manure after harvest, which, in this scenario of no cover crop leads to the high probability of nutrient leaching and run-off losses. With cover crops in the field, one can effectively spread manure in the fall and winter while avoiding the subsequent risk of nutrient loss from leaching and runoff (Abdalla et al., 2019). Non-legumes can be used to hold the nutrients when not required by the crop and release them through the process of decomposition in the subsequent season, while leguminous cover crops fix atmospheric nitrogen that can be utilized by subsequent crops. Cover crops can out-compete the weeds for light, moisture, nutrients and suppress weed growth (Lingenfelter, 2006).

Similarly, cover crops can also be used after a small grain harvest to improve soil health. Small grains such as wheat or barley are commonly grown in the Northeastern U.S. for grain and straw followed by a soybean crop. Double crop soybeans are those that are sown after harvesting a small grain in the same field in the same year (Rod et al., 2021). The success of double crop soybean depends primarily on two factors. First is adequate time for the production of the soybean crop and second is sufficient water whether it be moisture stored in the soil, or supplied through rainfall or irrigation (Shapiro et al., 1992). Often rushing for timely establishment of double crop soybean leads to early wheat harvest that entails drying and labor problems (Brink & McCarl, 1978). Further erratic changes in climate ranging from extreme drought to early frost are becoming more and more common and this has widely affected soybean yield (Yu et al., 2021). During dry summers, the risk of crop failure of double-cropped soybeans is high. Yields for soybeans have increased significantly as a result of a variety of technological and breeding improvements. However, a study conducted by Yu et al. (2021) isolated the effect of climate-related adaptation on soybean yield over 1951-2017 in eastern parts of the United States. And the study found significant negative impacts (up to 67 percent) on yield with soybean maladaptation to abnormal conditions, and the predicted decline in soybean production ranged from 68-92 percent by 2050, respectively.

Some cover crop species are more resilient to adverse growing conditions than double crop soybeans. They also present a potential adaptive strategy to climate change given the fact that cover crops better protect soils from erosion from extreme rain events, are more efficient in nitrogen retention at times of higher mineralization due to warming, and improve soil water management alleviating soil water excess or depletion (Dabney et al., 2001).

Further, double crop soybeans produce low amounts of fragile crop residue with a low C: N ratio that is quickly decomposed by soil organisms (Balkcom et al., 2007) and do not provide enough cover to protect the soil through the winter and spring (Ghimire et al., 2017). Also, there is little to no nitrogen production when the soybeans are planted late in the season as late soybean planting doesn’t provide adequate time for the plants to nodulate (Shober & Taylor, 2014). Cover crops grown to protect the soil and feed livestock may be more valuable than double-crop soybeans in the long term attributed to their forage biomass and soil health contribution (Lindsey, 2018). Also, new cover crop species, cultivars, and mixtures are constantly being evaluated, with the development of new establishment methods, increasing the likelihood of success (White, 2014). Given the advances, the 2016-2017 SARE survey (Clark, 2017) reported a 25% and 60% increase in U.S. cover crop area in the period 2016-2015 and 2016-2014, respectively.

1.2 Challenges to Cover Crop Adoption

Though cover cropping has been reported to increase soil organic matter and improve the productivity of eroded soil and overall soil health, the adoption of cover crops is still limited (Norris & Congreves, 2018). Successful cover crop establishment requires time, capital, labor, and management (Singer et al., 2007) along with the potential for reduction of following cash crop yield. Growing cover crops includes the cost of planting (seed, labor, fuel, equipment) and suppressing the cover crops (mowing, herbicide, tillage).

While making decisions to integrate cover cropping into a farming system, short-term economic profitability is an important factor influencing farmer decision-making (Cary & Wilkinson, 1997). Cover crops are a long-term investment since the ecological and soil health benefits of cover crops are long-term goals that take time to take effect (Poffenbarger, 2010) while the costs are immediate. In the 2016-2017 SARE survey, 53% of farmers reported that the additional cost of planting cover crops was a major challenge (Conservation Technology Information Center, 2020).

Cost and management constraints of cover crops continue to inhibit widespread adoption of this environmentally beneficial practice. To stimulate widespread adoption of cover crops farmers, need to realize immediate benefits such as revenue from the cover crop, subsidies, or rapid improvement in soil productivity. Local, state, and federal government agencies have adopted various strategies like cover crop incentive payments to promote cover crop use. Alternatively, cover crops are being harvested for silage and fed to livestock, but this comes with the cost to mow, rake, bale, store, and feed the forage. Thus, the big question remains the same, “what could be the immediate profit from cover crops to recoup their establishment and management cost”? The answer could be the exploration of the potential mutual relationship between cover crops and grazing animals, which can provide instant motivation and immediate incentive to the farmers given the return derived from grazing the cover crop.

1.3 Opportunities to Increase Cover Crop Adoption with Management intensive Grazing

Cover crop grazing can recoup the establishment cost of cover crops and increase overall farm revenue (Franzluebbers & Stuedemann, 2007). With the increasing world population, growing demand for grain, and climatic adversity, more and more grassland is being converted into cropland which has intensified the pressure to diversify the animal feed source through the utilization of crop residue and silage (Wimberly et al., 2017). Also, by encroaching on the land under pasture, the acreage under cropland is expanding and subsequently, the pressure to raise the livestock on limited native rangeland and pastureland has led to the deterioration of soil health, quality, and quantity of the vegetation (Tobin et al., 2020).

Amidst all these problems, cover crops can be utilized as quality nutritious forage for feeding ruminant livestock during fall and winter reducing the feed cost considerably (Klopfenstein et al., 1987; Clark et al., 2004). This extends the rest periods for perennial pastures and render effective utilization of those cover crops which would otherwise be left in the field to die (White, 2014). Also, during summer drought periods, it is hard to sustain livestock on cool-season permanent pastures which lead to additional costs for farmers for hay or haylage to feed livestock, and thus frequently results in overgrazed and degraded pastures (White, 2014). Instead, cover crops adapted to the heat of summer can be grazed, relieving pressure on cool-season pastures. Grazing can be more profitable than making silage as well the cost per ton of dry matter is half or less (Berger, 2017).

Adding a grazing component to cover crops could open new doors and increase cover crop adoption. Cover crops help with nutrient retention and provide high-quality forage. A study in West Sussex and Kent (UK) showed scavenging of 91 kg ha^{-1} and 86 kg ha^{-1} N by a mix of cover crops (mustard, rye, phacelia, and vetch) and winter turnip/rape respectively, and reported up to 2650 to 3685 kg ha^{-1} of dry matter regrowth within 16 to 60 days rest periods. Nutrient content in cover crop biomass varied from 56 to 74 kg ha^{-1} K_20 and 14 to 19 kg ha^{-1} P_2O_5 which became available to plants in following seasons while 349 to 546 kg ha^{-1} carbon returned to the soil (Shah et al., 2017). Franzluebbers & Stuedemann (2007) reported grazing of cover crops in grain cropping systems increased economic return and diversified agricultural production systems.

With grazing, farmers can explore the economic compatibility between cover crops and animal grazing. The integration of both practices can add immediate economic value to cover crops, which otherwise would have taken years to realize through improvement in soil quality (White, 2014). The need for herbicide and fertilizer could be reduced through grazing. The livestock in return add urine, manure, and saliva to the soil and the cumulative herbivory action has been found to stimulate soil biology (Hamilton & Frank, 2001). This promotes a continuous nutrient cycle within the farm where nutrients removed through plant grazing are added back to the soil and the additional animal manure improves soil structure, biological activity, and cation exchange capacity. Some evidence shows that cover crops with significant biomass can be the fastest way to build SOM and improve soil biology (Kim et al., 2020).

Cover crop grazing can be a potential way to enhance land-use efficiency, diversify crop production, soil microflora and fauna, farm profitability, and the overall sustainability of the agriculture system (Lemaire et al., 2014; Sparrow et al., 2003). Grazing cover crop does not remove the below-ground biomass which can continue its vital role in alleviating soil compaction, enhancing nutrient absorbing surface area, stabilizing soil structure, and sequestering soil C. In terms of accumulating soil organic carbon cover crop roots are pivotal contributing 70% to the total soil carbon pool compared to the above-ground biomass (Wilhelm et al., 2007). Also, cover crop grazing could fuel the growing interest in integrated crop-livestock production systems (Liebig et al., 2012). Therefore, cover crop grazing can be a motivation in integrated crop-livestock production through economic, environmental, and soil health benefits for the farmers. By allowing the ruminants to graze the cover crops, farmers can also reduce economic risk by diversifying their economic output (Poffenbarger, 2010).

Further, the benefits that can be drawn from cover crop grazing depend on forage biomass produced, cost of implementing grazing (fencing, water supply, cover crop establishment, management and termination cost), length of grazing period and most importantly grazing management. To draw maximum benefits from cover crop grazing, improved management methods are important. Management intensive grazing is often called adaptive grazing or prescribed grazing which is characterized by allowing animals to graze a piece of a paddock for a short period (e.g., 1 or 2 days) followed by a long rest period which gives plenty of time for vegetation regrowth until it is ready to be grazed again. Management intensive grazing can make the entire process low in cost with portable fencing, appropriate stocking density, and regular movement of animals between paddocks (Ericson, 2009). With management-intensive practice, cover crops can be grazed in a way that provides significant amounts of high quality feed to the livestock but at the same time leaves sufficient cover crop residue in the field required to protect soil from erosion and also maintains soil health (Blanco-Canqui et al., 2020).

The grazing technique for management intensive grazing of cover crops is based on the “take half, leave half” principle. Also, in the management intensive grazing of cover crops, there is even distribution of animal load and manure due to high stock density for a short duration and long rest periods so the potential for compaction is reduced while the potential for soil health improvement is maximized (Ericson, 2009). Under good management, the effect of animal grazing on soil compaction may disappear within weeks (Drewry, 2006).

Further, the resting period not only improves the regrowth and forage yield potential of cover crops but also the root proliferation and rooting depth of cover crops (Andrae, 2014). In the late fall when palatable and nutritious forage is limited, animal nutrition can be maintained by allowing them to graze green and nutritious cover crops. Also, numerous studies have documented the benefits of animal manure to the soil ranging from enhanced soil microbial activity, organic matter, improved soil structure, and water holding capacity, soil C and nutrient cycling, improved soil resilience to compaction, and more (Blanco-Canqui et al., 2020; Franzluebbers & Stuedemann, 2015). Some research has reported, under no-tillage or minimum tillage, management intensive grazing in fields with good cover crop stand can offset the potential issues arising from cattle grazing given the ground cover and anchoring capacity of the cover crop root system (Hamilton & Frank, 2001).

1.4 Effect of Grazing Cover Crop on Soil Quality Indicators

Grazing impacts on the soil, vegetation, and environment are generally viewed as negative (Nosetto et al., 2006; Sparrow et al., 2003) primarily with continuous grazing followed by poor management practices, including unrestricted access to pasture, high animal density on rangeland that leads to streambank erosion, soil compaction, and nutrient contamination through fecal deposition adjacent to and directly in water bodies (Bilotta et al., 2007). As a result of which conservation program managers and farmers have been hesitant to give the green light to the grazing of cover crops with fear of livestock induced soil compaction, nutrient pollution, and potential erosion. Grazing, if not managed properly, is one of the reasons for soil health degradation and reduction in agronomic production. Moreover, the effects of animal grazing on soil health are an interplay of site-specific climate and soil characteristics (soil organic matter content, soil texture, and structure, moisture content) and management aspects including animal density, animal size, grazing period, resting period, vegetation type and amount (Chanasyk & Naeth, 1995; Drewry, 2006). Thus, the idea to propose management intensive grazing of cover crops as a profitable and sustainable practice carries doubts and concerns with it as to its effect on soil health.

1.4.1 Effect of Grazing Cover Crop on Soil Physical Quality Indicators

Soil compaction is the primary concern for agricultural producers with grazing resulting from the trampling action and pugging by large ruminants (cattle). Soil compaction from grazing action is perceived as a serious threat by farmers and not without a reason since the pressure exerted by a stationary mature beef cow is more than 0.1 MPa and the pressure increases by 5-fold up to 0.5 MPa when the cow is walking which is greater than the pressure exerted by many farm vehicles i.e., typically 0.1 to 0.25 MPa (Betteridge et al., 1999; Halde et al., 2011). Compaction becomes even worse in wet conditions in the spring that exacerbate the effect of animal trampling. Under wet conditions, trampling by livestock even for a short period can inflict serious detrimental effects on soil properties such as macroporosity and soil structure which in turn affects the rate of water infiltration (Drewry, 2006). Morris et al. (1998) found higher bulk density from grazing cover crops in early spring compared to grazing during the summer due to higher moisture content in spring. Compaction with its multi-dimensional effect on soil properties (water infiltration, aggregate stability, macroporosity) can affect crop yield in the following season (Blanco-Canqui et al., 2020; Fernández et al., 2011).

Grazing cover crops can have a smaller negative effect on soil properties in continuous no-till systems compared with tilled systems, due to higher biological activity and more stable structure in no-till. However, results of higher bulk density for grazed plots were found in no-tillage systems also by Morris et al. (1998) and Tollner et al. (1990). Also, Franzluebbers & Stuedemann (2008) studied soil properties for the influence of grazing under conventional and no-tillage and in this study they found a slight increase in bulk density over time for the grazed cover crop field compared to the un-grazed cover crop field under no-tillage management. Though the value for bulk density was found to be higher for no-till systems compared to conventional tillage, the better ability of the roots to penetrate the soil seemed to explain higher crop yields resulted in the no till system given the data collected for penetration resistance.

Also, soil bulk density was mostly unaffected by grazing with values of 0.97 and 1.2 Mg m^{-3} at the end of 0.5 years and 0.99 and 1.4 Mg m^{-3} at the end of 2.5

years under un-grazed and grazed rye cover crop in no-till system respectively (Franzluebbers & Stuedemann, 2008). For the same study, higher penetration resistance was found to a depth of 30 cm after the first year under grazed treatment compared to ungrazed treatment, but penetration resistance decreased after the second year and in the third year, there was almost no difference. Similar results of small or non-existent increases in bulk density of grazing cover crops were reported by Franzluebbers & Stuedemann (2008) for short-term grazing.

Soil macroaggregate stability was studied for the influence of grazing under conventional and no tillage management by Franzluebbers & Stuedemann (2008). In the study, they found greater macroaggregate stability when grazed compared to the ungrazed system under no till system in some of the cases, while aggregate stability was lowered for the grazed system under conventional till. Also, no effect on aggregate stability was resulted from animal trampling under dry soil conditions of permanent pasture, while negative effects were observed when field conditions were wet (Warren et al., 1986).

1.4.2 Effect of Grazing Cover Crop on Soil Biological Quality Indicators

Soil biological activity can be affected by both the quantity and quality of added organic matter. Higher soil organic matter content typically means higher microbial biomass and greater activity. Likewise, with substantial carbon input from cover crops, an increase in soil microbial biomass and activity was seen (Buyer et al., 2010; Nair & Ngouajio, 2012). Soil microbial biomass carbon was increased with cover crop grazing at a depth of 0 to 30 cm as compared to no grazing under no tillage, and carbon dioxide (CO_2) flush increased for soil from a depth of 0 to 6 cm depth (Franzluebbers & Stuedemann, 2015). However, no effect of cover crop grazing was revealed for soil microbial biomass carbon under conventional till in this study. Higher soil microbial biomass carbon was reported under winter grazing cover crops compared to ungrazed winter cover crops but no difference in grazing treatment for total organic carbon was resulted between conventional till and no till (Franzluebbers & Stuedemann, 2008). A study by Tracy & Zhang (2008) found increasing total organic carbon and microbial biomass carbon over time under winter grazed corn-oat pasture system compared to continuous corn. Tobin et al. (2020)

found higher soil organic matter content for the ungrazed cover crop mix compared to the grazed cover crop mix in South Dakota. A grazing project conducted on 8 farms in Iowa and Minnesota studied the effect of cover crop grazing in integrated livestock production on soil health and compared it to a production system with no cover grazing (control). They documented higher total carbon where the cover crop was grazed on 7 of the farms (*Economic and Soil Health Impact of Grazing Cover Crops, 2018-2019*, 2020). With the influx of substantial carbon from the above and below ground cover crop biomass and manure from grazing, the microbial community of soil organisms and its activity is expected to increase with a grazed system (Nair & Ngouajio, 2012).

1.4.3 Effect of Grazing Cover Crop on Soil Chemical Quality Indicators

A study conducted by Tracy & Zhang (2008) reported increased total nitrogen for winter grazed corn–oat–pasture treatment over 4 years compared to the continuous corn with un-grazed cool-season cover crop system. Further, higher soil mineral nitrogen was showed for sheep grazed cover crop fields than un-grazed cover crops in Canterbury, New Zealand under conventional tillage (Francis et al., 1998). A study conducted by Tobin et al. (2020) of cover crop grazing, found increased total nitrogen content for the grazed treatment compared to un-grazed treatment at the depth of 0-5 cm. Increasing total nitrogen content with grazing in crop-livestock production systems has been reported in previous studies as well (Costa et al., 2015; Ganjegunte et al., 2005; Liebig et al., 2012). Galindo et al. (2020) studied two cropping systems (pasture-rye-soybean-pasture and pasture-wheat/vetch-corn-pasture) under the presence and absence of cattle grazing and showed improved soil quality and microbial decomposition in terms of increased available Ca^{2+}, Mg^{2+}, NO_3^-, NH4+, soil pH, soil C, S, and the C: N ratio under the grazed system in comparison with the ungrazed system.

1.5 Rationale for the Research

Reviewed studies suggest that cover crops can be grazed without serious detrimental effects on the soil, especially if done in continuous no-tillage systems where the soil is more resistant and resilient to soil compaction. However, the available studies carried out on the effects of management intensive cover crop grazing are still limited. Given the limited studies, the impact of cover crop grazing on soil physical and biological properties and economic benefit has yet to be understood better. Even to address the misconceptions/ benefits of management intensive grazing of cover crops on soil health, profit, and the environment, more study is required. Further, it is unclear how much the herbivory action and animal inputs (manure, urine, saliva) can compensate for the reduced plant aboveground biomass to promote management intensive grazing of cover crops as a sustainable approach that could collectively benefit the soil and the environment. Further, adequate information to the farmer concerning the effect of management intensive grazing of cover crops in long-term no tillage systems could help the farmers make informed decisions and overcome the barriers to the adoption of grazing of cover crops. These findings would also be of much interest to government organizations that subsidize cover crop adoption for environmental improvement.

To answer all these questions and to contribute to the research bank akin to cover crop grazing, it is important to evaluate and compare grazed with un-grazed cover crops in terms of the implications for soil biological and physical properties and provide facts to substantiate the idea that grazed cover crops could offer similar environmental and soil health benefits as non-grazed cover crops (Blanco-Canqui et al., 2020). Management intensive grazing of cover crops could be introduced as a best management practice (BMP) for soil conservation and environmental protection to progress towards sustainable agriculture if benefits are consistently confirmed. On a crop-livestock farm, cover crop grazing can potentially create a win-win situation for farmers and the general public by marrying conservation with profit. However, benefits need to be substantiated with scientific findings and economic interpretation. Thus, this research was designed to study and determine the impact of cover crop grazing in continuous no-tillage systems employing management intensive grazing strategies on soil physical and biological characteristics. Soil health was also investigated and compared for grazed cover crops and double crop soybean, followed by economic analysis of alternate scenarios.

1.6 Research Objectives

This research aims to evaluate the soil health, environmental and economic effects of cover crop grazing on four different farms in South Central Pennsylvania. The comparisons entail grazed versus un-grazed cover crops planted after corn silage and small grain harvest and grazed cover crops versus double cropped soybeans after small grain harvest (typically wheat). Specifically, the research objective was to:

a. Evaluate the effects of grazing cover crops on soil biological and physical properties (organic matter content, permanganate oxidizable carbon, carbon dioxide burst, bulk density, wet aggregate stability, and field saturated hydraulic conductivity).
b. Compare soil biological and physical properties after grazed cover crop with that after double crop soybean, both following small grain harvest.
c. Compare economic returns of alternative scenarios.

1.7 Research Hypotheses

a. Soil biological and physical properties will not be negatively impacted by management intensive grazing of cover crops after corn silage and small grain harvest in no-tillage systems.
b. If any, soil compaction due to grazing will only have a temporary effect (lasting < 2 weeks) and by that time soil will recover its original capacity given the biological activity in the soil.
c. Soil biological and physical properties under field conditions with grazed cover crops will be better in comparison to those under double cropped soybeans planted after small grain harvest.

d. Grazed cover crop after small grain harvest will result in a similar economic return as double cropped soybeans.

CHAPTER 2 MATERIALS AND METHODS

2.1 Study Area

Four farms located in Adams and Franklin Counties (2 in each county), Pennsylvania participated in the project. To identify each farm within a county, the farms were named as Adams 1, Adams 2, Franklin 1, and Franklin 2. For at least ten years, all farms have used continuous no-tillage as part of their recognized management strategy to improve cover crop grazing success. The climate data was taken in from a weather station located in Emmitsburg Maryland (16, 21, 55 and 76 km from Adams 1, Adams, Franklin 1 and Franklin 2 respectively). For 2020 the annual maximum and minimum temperature was 18 °C and 8 °C and annual precipitation was 941.1mm. The annual maximum, minimum temperature, and precipitation for the year 2021 were 18°C, 7 °C, and 995.21 mm respectively (NOAA National Centers for Environmental Information, n.d.).

The overall project was coordinated by the Capital RC&D Council and USDA-NRCS to provide infrastructure and resources to execute management intensive grazing of cover crops. Technical advice and grazing plans were developed in collaboration with the farmers by USDA-NRCS Grazing Specialists. The research was carried out by Penn State University with support from USDA-ARS.

With support from USDA-NRCS, the farmers set up fencing and watering systems in their fields. An exterior permanent fence was installed while portable electrified fences were used by the farmers to create small paddocks to obtain desired stocking density of animals. Water infrastructure was installed to provide water in each paddock. Typically, under management intensive grazing animals were allowed to graze in a designated paddock for 1 to 2 days after which they were moved to the next paddock while the previously grazed paddock was rested for a significant period before re-grazing. During the resting period, the plants recover and produce new growth. Visual observation of cover crop regrowth is important to determine the time of re-entry for effective utilization of the forage in the paddock. Individual farm description is listed below:

2.1.1 Adams 1

Adams 1 is located near Gettysburg, Adams County, southcentral Pennsylvania. The soil of the area of interest, based on the order of most acreage occupied, is dominated by fine-silty, mixed, active, mesic Typic Fragiaqualfs (Croton Series), fine-loamy, mixed, superactive, mesic Ultic Hapludalfs (Penn Series), and active, mesic Aeric Fragiaqualfs (Abbottstown series). These soils are classified as poorly drained, well-drained, and somewhat poorly drained, respectively (Table 2.1).

Table 2.1 Description of animals, grazed area, stocking density, cover crops planted, and their growth state at grazing for Adams 1 in 2020 and 2021.

Grazing season	Grazed Area	Area of individual paddock	Grazing period per cycle	Previous Crop	Grazed cover crop	Animal description	Stocking density	Crop growth stage at the start of grazing cycle
	ha	Ha	Days	Species	Species		Kg live weight ha^{-1}	
Spring 2020	4.9	0.33	15	Oats	Wheat	25 dry cows/ 454 kg 1 bull/ 907 kg	37142	Boot stage
Fall 2020	8.1	0.32	1st cycle- 25 2nd cycle -24	Wheat	Millet/brassica/sun hemp	24 cows/ 544 kg 24 calves/ 52 kg	43346	Vegetative, 81-91 cm tall
Spring 2021	8.1	0.48	17	Wheat	Rye/vetch/brassica cover crop	25 mature gestating dry cows/ 499 kg 6 pregnant heifers/408 kg 4 yearling heifers/ 340 kg	33923	Vegetative, 51-61cm tall
Fall 2021	4.5	0.31	1st cycle- 14 2nd cycle -15	Wheat	Sorghum Sudan	34 lactating cows/ 544 kg 33 calves – 68 kg 2 heifers – 363 kg	69245	Vegetative-30 inches tall

2.1.2 Adams 2

Adams 2 is located in Gettysburg, Adams County, southcentral Pennsylvania. The soils in Adams 2 are fine-loamy, mixed, superactive, mesic Ultic Hapludalfs (Penn Series) and active, mesic Oxyaquic Fragiudalfs (Readington Series) based on the order of most acreage occupied (Table 2.2). These soils are somewhat poorly drained and moderately well-drained, respectively.

Table 2.2 Description of animals, grazed area, stocking density, cover crops planted, and their growth state at grazing for Adams 2 in 2020 and 2021.

Grazing season	Grazed Area	Area of individual paddock	Grazing period per cycle	Previous crop	Grazed cover crop	Animal description	Stocking density	Crop growth stage at the start of grazing cycle
	ha	ha	Days	Species	Species		Kg live weight ha^{-1}	
Spring 2020	8.1	0.54	15	Corn silage	Red clover and annual rye grass	40 cattle /259 kg	19185	Mature clover and ryegrass
Spring 2021	4.05	0.41	1st and 2nd cycle -10	Corn silage	Rye grass and crimson clover	66 cattle/ 227 kg	36993	Vegetative -51-61cm tall

2.1.3 Franklin 1

Franklin 1 is located in St. Thomas, Franklin County, southcentral Pennsylvania. The soils in Franklin 1 are loamy-skeletal, mixed, active, mesic Typic Dystrudepts (Berks's series), mesic Lithic Dystrudepts (Weikert Series), and mesic Aeric Epiaquults (Clearbrook Series). These soils are well-drained, well-drained, and somewhat poorly drained, respectively based on the order of most acreage occupied (Table 2.3).

Table 2.3 Description of animals, grazed area, stocking density, cover crops planted, and their growth state at grazing for Franklin 1 in 2019, 2020, 2021, and 2022.

Grazing season	Total grazed area	Area of individual paddock	Grazing period per cycle	Previous crop	Grazed cover crop	Animal description	Stocking density	Crop growth stage at the start of grazing cycle
	Ha	Ha	Days	Species	Species		Kg live weight ha^{-1}	
Fall 2019	4.9	0.33	15	Wheat	Ray's crazy summer mix	4 heifer/ 363 kg 10 heifer/ 136 kg	8521	Vegetative
Spring 2020	1.6	0.12	1st cycle: 14 2nd cycle:13	Corn silage	Triticale	16 heifer/ 295 kg	39333	Boot
Fall 2020	26	1	26	Wheat	Ray's crazy summer mix	16 cattle/ 386 kg	6176	Vegetative-61cm tall
Spring 2021	1.8	0.1	18	Corn silage	Triticale, hairy vetch, and crimson clover	16 steers/ 544 kg	87040	30 cm tall, vegetative
Fall 2021	3.2	0.07	48	Wheat	Millet, sunflower cowpea	22 steers/ 295 kg	92714	Mature millet and cowpeas

2.1.4 Franklin 2

Franklin 2 is located in Mercersburg, Franklin County, southcentral Pennsylvania. The soil of area of interest is dominated by fine-loamy, mixed, semiactive, mesic Typic Hapludalfs (Nollville Series), where the soil is well-drained (Table 2.4).

Table 2.4 Description of animals, grazed area, stocking density, cover crops planted, and their growth state at grazing for Franklin 2 in 2020.

Grazing season	Grazed Area	Area of individual paddock	Grazing period per cycle	Previous crop	Grazed cover crop	Animal description	Stocking density	Crop growth stage at the start of grazing cycle
	ha	ha	Days	Species	Species		Kg live weight ha^{-1}	
Spring 2020	2.8	0.47	6	Corn silage	Wheat	18 brood cows/454 kg 7 spring calves, 4 heifers, and 2 steer calves/272 kg	24911	Boot stage 25-31 cm tall.

2.2 Data Collection Details and Procedures

The farmers, with assistance from Capital RC&D Council and USDA-NRCS, installed permanent fencing and water lines around and in their crop fields, acquired mobile fencing and watering supplies, developed a grazing plan, and learned about grazing cover crops. Crop fields had permanent exterior fencing and electrified interior mobile fencing and mobile watering systems so that a section was grazed one day after which animals were moved to the next section without the ability to return to the previously grazed section.

For this research, we studied two experimental scenarios. The first experimental scenario was evaluating soil health following management intensive grazing of cover crops after corn silage and small grain harvest. For this, we began preliminary field sampling in September 2019 while the farmers were trying to get their hand on the implementation of management intensive grazing of cover crops in a learning phase. Later in the spring of 2020 when all the farmers were aligned and started implementing their grazing plans, we collected samples from all four farms. Therefore, the first analysis didn't include soil health data collected from Franklin 1 in 2019. The research took into account biomass yield and forage quality data for forage sample collected since fall of 2019 to 2021. For spring 2020 grazing (after corn silage harvest) samples were collected for Franklin 1 in April, Adams 1 in May, Franklin 2 and Adams 2 in June. While for spring 2021 the samples for Franklin 1 were collected in May and for the other farms in April. For the fall cover crop grazing, we had only two farms (after small grain harvest scenario), because the other farmers did not grow small grains. Fall sampling for Franklin 1 was carried out in September of 2019 and 2020 and October of 2021. While for Adams 1 fall samples were collected in September for both years (2020 and 2021). Farmers would inform the research team when they started grazing the cover crop field of focus. The research team would then travel to that farm to take samples and do field measurements in parts of the field that were un-grazed, grazed the day prior, and grazed at least 2 weeks earlier.

The second experimental scenario compared the soil health and profitability impacts of management intensive grazing of cover crops with double cropped soybeans after small grain harvest. For comparison of soil health and economic analysis between management intensive grazing of cover crops and double crop soybean, soil physical, and biological properties, and forage biomass was collected from Franklin 1 in September of 2019 and 2020, and October of 2021. While for Adams 1 samples were collected in October of 2020 and September of 2021. In 2019, we didn't have the double crop soybean scenario on Franklin 1, and we considered the data collected from full-season soybean fields and compared it with cover crops grazed a month ago. The economic value and soil health following double crop soybean harvest was studied primarily to evaluate and compare with management intensive grazing of cover crops and see if it would result in similar soil health implications or in fact better given the addition of livestock manure, crop residue, and herbivory action and at the same time provide a comparable economic return. Soil sample and infiltration measurements were collected from fields where cover crops, planted after small grain harvest, were grazed approximately one month earlier and from fields where soybean was harvested in 2019, 2020, and 2021.

Soil and forage samples and infiltration measurements were taken in 4 random spots in each cover crop and soybean section. Soil samples were only collected from 0-10 cm because the effect of grazing on the soil is usually found to be limited to the surface 10 cm (Franzluebbers & Stuedemann, 2008). Bulk soil samples were collected with a sharpshooter spade. Care was taken to collect a vertical slice of soil that had uniform thickness from top to bottom so that the same amount of soil from the top as from the bottom was collected. Further, four core samples were collected for bulk density determination. Bulk soil samples were air-dried, ground, and passed through a 2 mm sieve for total carbon, aggregate stability, and Permanganate Oxidizable Carbon (POXC) analysis and through an 8 mm sieve for soil CO_2 burst analysis. Permanganate Oxidizable Carbon was measured by using 0.02 mol L^{-1} KMnO4 that measures the 'active C' fraction from the total soil organic carbon developed by (Weil et al., 2003). Soil CO_2 burst was measured using the sealed chamber alkali trap respirometry method (Schindelbeck, et al., 2016) . Bulk density was determined using 7.6 cm diameter x 7.6 cm high soil cores (Peng et al., 2017). The soil from the top and bottom of each metal cylinder was trimmed off and the soil was subsequently dried at 105 ^{o}C until a constant weight was obtained. Then, the soil was washed through a 2 mm sieve and all fragments resting on top of the sieve were collected, dried, weighed, and their volume determined with the water displacement method. The bulk density of the fine earth fraction was subsequently calculated after the weight and volume of the coarse fragments had been subtracted. Aggregate stability was measured using 4 g of 1-2 mm soil held in the sieve of a wet sieving apparatus which is designed to lower and raise the sieve 1.3 cm for about 35 times/min for a total of 3 min ± 5 sec in order to measure the structural stability of soil (Józefowska et al., 2021; Six et al., 1999). Field saturated hydraulic conductivity ($Kf\,s$) was determined in the field using SATURO Dualhead Infiltrometers (Nimmo et al., 2009). Settings for measurement of Kfs were low pressure –5 cm, high pressure -10 cm, pre-soak time - 15 minutes, 2 pressure cycles, hold time of 15 minutes, with a total run time of 75 minutes.

For biomass measurement, forage samples were cut to the soil surface from 0.5 m^2 areas (replicated 4 times) and dried at 55 ^{o}C until a constant weight was recorded to obtain the dry biomass. Standing cover crop biomass was determined from the ungrazed cover crop section while remaining cover crop biomass was determined in the recently grazed section so that grazed biomass could be calculated by difference. A forage quality sample was taken by harvesting a representative sample of the cover crops 15 cm above the soil surface (Zhang & Redfeam, 2017) or at the soil surface based on observations of grazing habits of the animals, stored at -4 ^{o}C to -9^{o}C temperature until sent to the lab for quality analysis. Forage quality was analyzed by Cumberland Valley Analytical Services Laboratory for acid detergent fiber with Fiber (Acid Detergent) and Lignin in Animal Feed (973.18) procedure (Goering & Van Soest, 1970). Metals and minerals were analyzed with Metals and Other Elements in Plants (985.01) procedure (Goering & Van Soest, 1970) and total dry matter with partial dry matter procedure modified as per National Forage Testing association recommendations, 2002 (Rushing et al., 2016).

2.3 Laboratory Analysis for Soil Physical, Biological Properties

2.3.1 Preparation of Bulk Soil Samples

Bulk soil samples were crumbled by hand, spread over a tray, and labeled with their respective sample ID. They were frequently turned in a greenhouse for 4-5 days until air-dry and then ground and sieved (using size sieve as per required test) for further analysis.

2.3.2 Soil Fertility Analysis

The air-dried soil sample was crumbled by hand after which soil clods were crushed with a hammer to pass through a 2mm sieve. The sieved samples were submitted to the Pennsylvania State University Agricultural Analysis Laboratory for analysis. The soil was analyzed for available P, K, Ca, Mg, Zn, Cu, S, pH, and CEC (Table 2.5). The pH (H_2O) was measured in 1:1 soil: water mix (Eckert & Sims, 2011), extractable P, K, Ca, Mg, Cu, S, and Zn were measured with ICP after Mehlich-3 extraction and CEC calculated with summation method (Wolf & Beegle, 2011).

Soil analysis is a strategy for effectively managing soil nutrients such as phosphate (P), potassium (K), and magnesium (Mg) in plant-available forms in order to maintain soil fertility (Barnwal et al., 2021). The pH for most farms was within the optimum pH range of 6-7 for 0-10cm depth. While, for Adams was it was below 6 which put Adams in less advantaged situation in terms of soil health compared to other farms. The optimum level of potash in the soil is 2-3.3 percent of the cation exchange capacity (CEC), which varies depending on the management practices used on a specific farm. All farms showed above-optimal K levels, except for Adams 1 which might be attributed to acidic field condition. One of the most important elements affecting soil microbial abundance is soil pH. Acidification of soils in organic farming has a substantial impact on total nutrient bioavailability and soil microorganism catabolic function (Eckert & Sims, 2011).

Table 2.5 Soil fertility analysis (0-10) cm depth of four Pennsylvania farms used in this study from 2019-2021.

Year	Farm	pH (H_2O)	P	K	Mg	Ca	Acidity	CEC	Mg Saturation of CEC	Ca Saturation of CEC	Zinc	Copper	Sulfur
			ppm	ppm	ppm	ppm	Meq/100g	Meq/ 100 g	%	%	ppm	ppm	ppm
Fall 2019	Franklin 1	6.2	69	216	161	1132	3.2	10.79	12.46	52.50	4.34	5.14	9.30
Spring 2020	Franklin 1	6.2	119	227	158	1735	3.0	13.51	9.79	63.52	4.92	6.55	12.73
	Adams 1	5.2	39	91	33	403	5.8	8.33	3.29	24.25	0.86	1.77	13.21
	Adams 2	6.7	90	157	184	1518	1.7	11.19	13.73	67.95	6.73	4.42	13.42
	Franklin 2	5.7	99	96	107	623	5.6	9.81	8.95	31.61	3.60	0.95	16.38
Fall 2020	Franklin 1	6.5	97	165	187	2394	3.1	16.63	9.38	69.45	5.43	7.69	14.33
	Adams 1	5.9	46	71	70	1096	5.1	11.37	5.12	48.56	1.29	1.56	11.26
Spring 2021	Franklin 1	6.4	91	302	254	1786	2.3	14.13	14.79	63.12	4.18	5.27	9.93
	Adams 1	5.9	52	129	94	998	3.3	9.42	8.45	51.27	1.90	1.95	10.78
	Adams 2	7.2	90	94	214	1615	0.2	10.28	17.48	78.66	6.88	4.64	18.38
Fall 2021	Franklin 1	6.3	96	221	189	1704	2.7	13.36	11.69	63.09	3.98	7.61	10.56
	Adams 1	5.4	44	88	62	707	5.0	9.31	5.50	37.41	1.56	2.09	17.29

Analysis of soil physical and biological properties was performed in Penn State and USDA-ARS laboratories (with exception of field saturated hydraulic conductivity that was measured in the field). Soil physical (bulk density, wet aggregate stability, field saturated hydraulic conductivity), chemical (Total C and N), and biological properties (soil CO_2 burst, Permanganate Oxidizable C, soil organic matter content) were determined to study the effects of grazing cover crops on soil health.

2.3.3 Determination of Bulk Density

Materials required

- Core sampler
- Knife
- Weighing balance
- Metal Cans
- 50 and100 ml graduated cylinders
- 2mm sieve

To evaluate the effect of cover crop grazing on soil compaction, we studied the bulk density of soil. Bulk density was determined using the core method (Grossman & Reinsch, 2002). A core sampler was used to obtain a 7.6 cm diameter x 7.6 cm high soil core for bulk density from the depth of 0-10 cm. For this, the core sampler was taken and pressed vertically into the soil surface far enough to fill the sample but not too deep to avoid soil compression within the confined space of the sampler. After that soil around the core was excavated without disturbing or loosening the soil inside the core and then the core was carefully removed by keeping the soil intact in it. Then core samples were wrapped in saran wrap, kept in the cooler after being marked with the date and location where the sample was collected. A total of 4 core samples was collected for each treatment and stored at 4-6 ^{o}C until they were processed in the lab. The top and the bottom of the core were trimmed to obtain a flush surface with the top and bottom of the core, pushing the soil in the core as much as possible to the top to remove as little surface soil as possible from the top. If there was a stone sticking out of it, it was removed, and the hole was packed with trimmed soil from the same surface. After trimming the core was placed in a container and placed in the oven at 105ºC until a constant weight (M_{solids}) was obtained. The oven-dry weight of the soil was recorded. The volume of the core was determined using the following formula:

Ring volume (cm^3) = 3.14 x r^2 x ring height, where r = inside radius of core (3.81 cm) and ring height = 7.62 cm.

Coarse fragments and gravel have a significant effect on the mechanical and hydraulic properties of soil and if included in bulk density measurements lead to faulty measurement of the bulk density for soil that has more than 10% coarse fragments (McKenzie et al., 2002). Therefore, the bulk density of the fine earth fraction was calculated by correcting for coarse fragments. For this, the oven-dried soil was passed through a 2mm sieve, and the material left on the top of the sieve (greater than 2mm) was collected (coarse fragments and gravel). The >2mm coarse fragments were washed and air-dried to a constant weight. The weight of the coarse fragments was then recorded. To determine the volume of coarse fragments, a graduated cylindrical flask with a known volume of water was taken and the coarse fragments were added. The amount of water displaced by the coarse fragments in milliliters is equal to the volume of the coarse fragments.

The equation to determine the bulk density of the fine earth fraction is:

Bulk density of fine earth fraction = [Oven dry weight of soil in the cylinder (g) – Air dry weight of coarse fragments (g) / [Volume of the cylinder (cm^3) – Volume of coarse fragments (cm^3)].

2.3.4 Determination of Wet Aggregate Stability

Materials required

- Weighing balance
- Soil aggregate dunker
- Metal Cans
- Sonifier
- Distilled water

Wet aggregate stability (Kemper & Rosenau, 1986) was determined on air dry bulk soil samples collected from 0-10 cm depth that was passed through a 2 mm sieve but stayed on top of a 1 mm sieve. A pre-weighed can labeled as can A was filled 3/4th with deionized water. Subsequently, a sieve with a 0.5 mm aperture was filled with approximately 4 grams of the 1-2 mm air-dried aggregates. Sieves, can A, and can B of each sample were given numbers to keep track of the sample. The empty weight of the numbered can A and can B were pre-recorded.

The small sieve with 1-2 mm aggregates was then placed in the recessed holders of the wet sieving apparatus such that the soil was just wetted in the highest position of the rack in the sieving apparatus. After that, 3 technical replicates of each sample, to a total of 12 from each treatment (there being 4 experimental replicates), were placed in the apparatus. After that, the assembly was lowered, and the motor was started for 3 min ± 5 sec. The sieve was lowered and raised 1.3 cm about 35 times/min. After 3 min the motor was stopped, the sieves were taken out of the water and the numbered cans A were placed in a tray that contained the soil that passed through the sieve.

The numbered sieves were then placed in their respective pre-weighed can B. Distilled water was poured in Can B, enough to immerse the soil aggregates, and then the sieve was placed at the bottom of an ultrasonic probe, and it was held in the position for about 30s at a medium frequency which disintegrated the aggregates into the primary particles. The aggregates were also rubbed gently against the screen to make sure all aggregates were dispersed. Once the gritty texture of the sand was felt and no more fines were released, the sonicator was stopped. The sieve was rinsed by gently pouring distilled water from the top of the screen. Sand particles, too large to get through the screen were left on the top of the screen. The material that passed through the 0.5 mm sieve was collected in Can B that was placed in a tray.

Now both the sets of trays that contained the Can A and Can B were placed in the oven at 110 ºC until all of the water in both of the cans was evaporated. After they were oven-dried the weight of the numbered can A and can B was recorded. The weight of materials in can A and can B was determined by subtracting the oven-dried weight of the cans with soil with that of the weight of the empty cans.

Percentage Wet aggregate stability was determined by using the following equation:

Percent water stable aggregates = 100 x [Oven dry weight of can B w. soil - empty weight of can B] / [(Oven dry weight of can B w. soil - empty weight of can B) + (Oven dry weight of can A w. soil - empty weight of can A)].

2.3.5 Determination of Field Saturated Hydraulic Conductivity

For this research, SATURO Dualhead Infiltrometers were used to automatically measure field saturated hydraulic conductivity (*Kf s*). With the multi-pressure head analysis approach, the SATURO makes it easy to simplify the corrections for three-dimensional flow from a single ring infiltrometer and automatically calculates saturated hydraulic conductivity, reducing the errors as associated with hydraulic conductivity assessment (Reynold and Elrick 1990).

Before installing the SATURO infiltrometers rocks, sticks, and large debris were cleared from the soil surface without disturbing the soil and the 15.24 cm (6”) inner diameter insertion ring was placed on the spot chosen. A driving plate was placed on top of the insertion ring and hammered at the center (the inner circle) until the ring was inserted to a depth of 5 cm, taking care not to compact the soil and ensure a tight contact, without any gaps between the soil and ring sidewall. The driving plate was removed, any dirt or debris was cleared from the lip of the insertion ring and the infiltrometer head was clamped onto the insertion ring to form a seal.

Care was taken to clamp the ring gently to the infiltrometer head, avoiding warping of the insertion ring by tightening too much, or not making a good seal if too loose, which both would result in inaccurate pressure readings. A flathead screwdriver was used to loosen or tighten the clamps. After installing the infiltrometer head, the hose and sensor cable were connected to designated fitting, which can easily be identified by looking at the size of the input and output line. Now the water tanks were filled and connected to the control unit and the water valve was opened. The control unit was then put on a sturdy level surface, and the relevant hose and sensor cable were connected to the connecting unit. The control unit was then turned on by selecting the power option. To open the test setup screen, ENTER was pressed and the test name was manually entered. Once the test name was assigned the done option was selected and the settings for the test were entered. The following settings were used to measure field saturated hydraulic conductivity:

Insertion depth: 5cm
Low pressure: 5cm
High pressure: 10cm
Pre-soak time: 15 minutes
Pressure cycles: 2
Hold time:15 minutes.
Total run time: 75 minutes

After finalizing the setting to begin the test enter was pressed. During the test, the control unit was regularly checked for any malfunction, faulty pressure reading, or leakage. If a run was faulty, it was discarded, and a new test was initiated in a new location. Once the run time of 75 minutes was completed, the control units automatically stop. To retrieve the data from the control unit, the SATURO downloader app was installed. The USB cable was connected to the USB port on the computer and the SATURO unit, the application was opened in the computer and the data was downloaded.

2.3.6 Determination of Soil Carbon dioxide burst

Materials required

- Clean dry mason jars with lids.
- Filter papers, grade 1, 85mm circle
- Labeling tape
- Sharpie
- Pre-perforated aluminum weigh boats
- Weighing papers
- EC meter

Preparation of CO_2 trap:

To determine soil carbon dioxide burst (Schindelbeck, et al., 2016) two filter papers were placed in the bottom of sealable respiration jars and adjusted by using forceps to uniformly cover the bottom of mason jars. Twenty grams of air-dried soil passed through an 8mm sieve was weighed into a pre-perforated aluminum weigh boat and placed inside the jar using forceps. A weigh paper was placed below the weigh boat on the balance pan such that soil falling through the perforations in the bottom of the boat was collected and poured back into the aluminum weigh boat. We included 2 technical replicates per sample, for a total of 8 per treatment since there were 4 experimental replicates, written as ‘a’ and ‘b’ after the particular sample number in the jar. Then pizza stools were placed on the top of the boat.

After this 9 mL of 0.5 mole potassium hydroxide (KOH) was pipetted into 20 ml trap beakers, which were placed on a trap assembly into each respirometer jar and the legs of the pizza stool were pressed into the soil sample to allow it to firmly stand and confirm to the slight dome shape of the jar bottom. Subsequently, 7.5 mL distilled water (H_20) was dispensed using an automated pipette onto the wall of the jar by holding the tip of the pipette against the wall of the jar. The tip of the pipette was inserted as far down as possible and not allowed to contact anything else in the jar. This called for extreme caution to avoid splattering of H_20 droplets into the trap beaker which would dilute the potassium hydroxide solution or drip the H_20 directly into the soil rendering the measurement faulty. After the water had been dispensed in the respirator jar, a flat lid was placed onto each jar. Placing the lid immediately onto the jar minimizes the time period for which the jar is open, thus preventing unnecessary CO_2 absorption from the room air. To keep balance among the time difference for which the jars are open, it is better to work in sequence and keep a blank jar in between the sample jars, this ensures more or less similar exposure time for the jars in one sequence. Then the jars were closed securely with the top rings and an airtight seal was ensured. Now, the jars were set up for incubation in a set of 11 jars for convenience (10 samples plus a blank) inside the growth chamber for 4 days at a temperature of 20 degrees centigrade.

To measure the electrical conductivity (EC), we calibrated the EC meter using standard solutions (692 ppm as NaCl of concentration 1413 µS/cm and 7230 ppm as NaCl of concentration 12.9 mS/cm). After calibration, the EC meter was ready to use. The rings from the jars were removed allowing the flat lid to seal the top of the jar. When ready to measure the sample, the lid from the jar was removed and the probe of the EC meter was placed inside the trap beaker containing the KOH solution and it was gently stirred. When the reading in the EC meter was stabilized, it was noted down for each sample. After each reading, we blotted the probe dry using Kim wipes. Caution: Blot the probe but don’t wipe it and do not let KOH dry in the probe.

Calculation of CO_2 burst: Based on the volume and concentration, the trap capacity for CO_2 absorption was calculated. When fully saturated 0.5 M of potassium hydroxide (KOH) can absorb sufficient CO_2 to become 0.25 M potassium carbonate (K_2CO_3) and one-half mole of CO_2 is accommodated by one mole of KOH. Numerically,

9 ml of 0.5 M KOH can accommodate

0.009 L * 0.25 mol/L * 44.01 g/mol * 1000 mg/g = 99.025 mg CO_2

From the total trap capacity (theoretical) of 99.025 mg CO_2, some fraction is absorbed. The total absorbed trap capacity proportion is equivalent to the proportion of the total conductivity drop that would be observed (between the EC of the 'raw' 0.5 M KOH and the EC of 0.25 M K_2CO_3) if the trap were saturated, which in turn is observed.

In simple terms: Observed EC drop = The difference between the measured EC for a sample (or blank) and the EC of the 'raw' KOH. After incubation is over, the measured drop in EC will be a fraction of the total possible EC drop which is called Full Capacity EC drop. This fraction represents the CO_2 absorbed by the KOH solution during the incubation period,

ECraw = Electrical conductivity of pure 0.5 M KOH

ECsat = Electrical conductivity of 0.25 M K_2CO_3

ECsample = Electrical conductivity of the trap associated with a particular sample,

and P = Proportion of the trap capacity for CO_2 absorption

P = ((ECraw – ECsample)/ (ECraw – ECsat))

The equation to determine the amount of CO_2 absorbed by the trap in mg is given below.

P*(trap capacity in mg) = amount of CO_2 in mg absorbed by the trap.

This gives the amount of CO_2 absorbed from an incubation of 20 grams of soil which when multiplied by 50 gives the amount of CO_2 burst in mg/ kg of soil.

2.3.7 Determination of Total Carbon and Nitrogen

For total carbon and nitrogen analysis (Wright & Bailey, 2001), the CN Elementar analyzer was prepared for analysis and checked for necessary maintenance (i.e emptied crucible drawer, repacked combustion/post-combustion/reduction/drying tube columns). Following the leak test, standards were prepared for analysis. Appropriate standards were in carousel positions 1-10. Position 1 and 2 were kept blank with RunIns in 3-5, Aspartic acid in 6-8, and two different soil standards in 9-10.

Empty crucibles were tared and the standards were weighed. The blanks were empty with 100mg being entered as sample weight. For the RunIns (Hagerstown soils), approximately 1 gram of a Hagerstown soil standard was taken. 150-200 mg of certified Aspartic acids reagent was measured. After that, soil samples were prepared for analysis. The soil was ground, airdried, and sieved through a 2 mm sieve. The appropriate sample ID was then entered in the next available carousel position. The empty crucible was tared and approximately 1g of well-mixed sample was weighed. The sample weight was recorded within the software. A known soil standard was included after each set of 10 unknowns and at least one known soil standard at the end of each full run.

Auto analysis: The CN Elementar began with the blank in position 1, and calibration was completed after running the last aspartic acid in position 8. All soil standards and unknown sample calculations were determined based on this initial calibration.

Data review after completion of the run: Ten unknown soil samples were run (at least two from each farm) to determine a general range of expected % N and % C, and then soil with reported % N and % C values on the low, median, and high interval of that range were selected. In the process, the Hagerstown (HAG) soil represented the low standard, NAPT 2019-116 was the median standard, and NAPT 2020-106 was the high standard. Reported % N and % C values of soil standards were checked against reported value intervals. If values fell within the accepted range, data for all unknowns run before this standard was accepted. And if values fell well outside of the accepted range, data for unknowns ran immediately before this failed standard, and all those run after were not accepted.

2.3.8 Determination of Permanganate Oxidizable Carbon

Materials required

- Handheld colorimeter, (generic 550 nm pocket colorimeter II, Hach® Company)
- Glass cuvettes (vials) for spectrophotometer
- Graduated polypropylene conical centrifuge tubes (50 mL)
- Weighing balance and pipette
- Rack to hold centrifuge conical tubes in an upright position
- Distilled water in the sealable squeeze bottle.
- Kim wipes for wiping cuvettes
- Preparation of 0.2M KMnO4 stock solution

To determine Permanganate Oxidizable Carbon (Weil et al., 2003) 11.09 g $CaCl_2$ was dissolved in ~750 ml distilled water in a beaker. To dissolve completely, stir the beaker continuously (final concentration, 0.1 M). Then 31.61 g $KMnO_4$ was mixed with 200 ml of distilled water. Both solutions were mixed and completely dissolve the solution, it was stirred for an hour. Then the pH of the final solution was measured. Depending on pH measurement, a dilute (~0.1 N) acid or base solution was prepared using HCl or KOH. Through a pipettor acid or base was slowly dispensed while monitoring pH, until it reached 7.2. The final solution was poured into an amber bottle (as the solution is light-sensitive) after bringing the volume to 1000 ml with distilled water and labeled properly. Preparation of standard solutions: 0.005, 0.01, and 0.02 M $KMnO_4$ in 0.1 M $CaCl_2$. To make the standard solution 1.25, 2.50, or 5.00 mL of the 0.2 M $KMnO_4$ stock solution was added to respective centrifuge tubes and filled with distilled water up to the 50 ml mark.

Preparation of standard curve: The round glass 20 ml glass cuvette was filled with distilled water up to the white mark (15 mL) and the outside of the vial was wiped with Kim wipes and then placed in the colorimeter. Once the cover of the colorimeter was placed, the zero buttons on the meter were pressed and the LED showed the reading of “0.00”. Then 3 centrifuge tubes were labeled, and their ID recorded. Now, 45 mL of distilled water was filled in three clean graduated centrifuge tubes. Using the pipette, 0.5mL of the 0.005 M $KMnO_4$ standard solution was drawn and emptied in the 3 different correspondingly labeled centrifuge tubes and then filled up to the 50 mL mark with distilled water. Every time the pipette was filled and emptied 2 to 3 times with the diluted solution, to completely remove the residual $KMnO_4$ solution. Now, 15 mL of the diluted solution was added to the 20 mL glass cuvette. The glass cuvette with distilled water was removed from the colorimeter and the glass cuvette with the standard solution was inserted. Before the reading was taken the outer surface of the glass cuvette was wiped with Kim wipes, placed in the colorimeter, the lid was closed, and the red button was pressed. The final reading of absorbance for the standard solution was noted. The same colorimeter reading procedure was repeated for the other two duplicates.

The above-mentioned steps were the same to determine absorbance for 0.01M and 0.02M $KMnO_4$ standard solutions except that in the process the solution of 0.05 M $KMnO_4$ was replaced with for 0.01M and 0.02M $KMnO_4$ standard solutions. A standard curve with absorption was plotted with absorbance on the x-axis and concentration on the y–axis.

Procedure: 2.5 g air-dried soil was weighed twice to a constant weight into an aluminum foil. 2.0 mL of the 0.2M KMnO4 was pipetted into a clean 50 mL graduated polypropylene conical centrifuge tube and was filled with distilled water up to the 20 mL mark. The tube was capped and swirled to mix the solution thoroughly. 2.5 g air-dried soil was added to the tube which was capped tightly. Samples were usually run in a set of 6 at a time and the tube holders were shaken vigorously using the platform shaker (about 120 strokes/min = 2 per second) for exactly 2 min. Then the tubes were allowed to stand in the rack for 10 min, this standing time allowing the soil to settle. Care was taken not to disturb the sample during the settling time and also not to expose the tubes to direct sunlight. During the settling time, the $CaCl_2$ in the solution caused the soil to flocculate and sit at the bottom of the tube.

While the tubes were left to settle, another set of 6 clean and empty 50 mL graduated polypropylene conical centrifuge tubes was filled with 45 ml distilled water each. After 10 min of standing time, a clean pipette was used to draw 0.50 mL of liquid from the upper 1 cm of the soil–$KMnO_4$ suspension (avoid floating debris), and this was transferred to the tube filled with 45 ml distilled water. The pipette was filled and emptied 2 to 3 times with the diluted solution, to completely remove the residual KMnO4 solution. Once the distilled water was added to the solution to fill it up to the 50 mL mark, it was capped and slightly shaken. Now, 15 mL of the diluted solution was added to the 20 mL glass cuvette. Before the reading was taken the outer surface of the glass cuvette was wiped with Kim wipes, placed in the colorimeter, closed and the final reading of absorbance for the sample was noted.

Calculations: For the standard curve linear regression equation was plotted with concentration as the dependent variable (y) and absorbance as the independent variable (x) and from this standard curve, the slope (b) and y-intercept (a) were determined.

Concentration = a + b * (absorbance).

The amount of oxidizable C in the soil sample is directly proportional to the bleaching (loss of purple color; reduction in absorbance) of the $KMnO_4$ solution. The lower the absorbance reading, the greater is the $KMnO_4$ color loss and subsequently the higher the amount of oxidizable C in the soil. To determine the oxidized C amount, it was assumed that 1 mol MnO_4 is consumed (reduced from Mn7+ to Mn2+) in the oxidation of 0.75 mol (9000 mg) of C. 0.02 mol/L was the initial solution concentration; 9000 was the mg of C (0.75 mol) oxidized by 1 mol of MnO4 changing from Mn^{7+} to Mn^{2+}; 0.02 L was the volume of $KMnO_4$ solution reacted, and 0.0025 was the kg of soil used.

POXC (mg kg^{-1}) = [0.02 mol/L - (a + b * absorbance)] * (9000 mg C/mol) * (0.02 L solution/0.0025 kg soil).

2.4 Grazing yield and Forage Quality

The grazed yield was determined each time the cover crop was grazed by harvesting all aboveground biomass from a 0.5 square meter area, replicated 4 times, before and after grazing. The biomass was cut at the soil surface, dried at 55°C until a constant weight was recorded, and weighed to obtain the dry biomass. The amount of forage consumed by the animals was obtained by calculating the difference between pre-and post-grazing at each grazing in kg ha^{-1} (Holechek, 1988).

A forage quality sample was taken by harvesting a representative sample of the cover crops 15 cm above the soil surface (Zhang & Redfeam, 2017) or at the soil surface based on observations of grazing habits of the animals, stored at -4 °C to -9°C temperature until shipment and was sent to the lab for quality analysis. Forage quality was analyzed by Cumberland Valley Analytical Services Laboratory for acid detergent fiber with Fiber (Acid Detergent) and Lignin in Animal Feed (973.18) procedure (Goering & Van Soest, 1970), metal and minerals with Metals and Other Elements in Plants (985.01) procedure (Goering & Van Soest, 1970) and total dry matter with partial dry matter procedure modified as per National Forage Testing association recommendations, 2002 (Rushing et al., 2016).

2.5 Economic Analysis

The economic analysis of the implementation of Management intensive grazing of cover crops was carried out using partial budget analysis. The partial budget analysis offers the flexibility to analyze the economic cost and benefit of a new practice by incurring only the change in the cost and return as a result of the implementation of Management intensive grazing of cover crops without having all the cost and return information of the entire production system (Cornelisse, 2017; Tigner, 2018).

Partial budget analysis was calculated using cost and revenue from the change of double cropped soybeans to grazed cover crop and it was divided into positive and negative effects. The added income and reduced cost from the implementation of management intensive grazing of cover crops fall under the positive effect and the incurred cost and reduced income in the process of implementation of management intensive grazing of cover crops fall under the negative effect. The net effect shows the difference in profitability or loss between the existing practice and management intensive grazing of cover crops practice.

The cost generated or lost was calculated based on the assumption that the farmers had the same number of animals on the farm with the management intensive grazing practice or the existing practice. To keep track of the cost incurred in the implementation of management intensive grazing, farmers recorded the cost of cover crop establishment and management (labor, seed, planting, and termination), grazing installation (water, fencing, labor). The cost involved in installing water system and fencing was spread over 5 and 10 years respectively and the total area covered was taken into account to calculate the cost of fencing and water supply on a month/ha basis. To compare the cost of cover crop grazing with double crop soybean, the cost of soybean establishment and management (labor, seed, planting, and harvest) and the subsequent income from the sale of the soybean yield were recorded. The cost savings from feeding cover crops were determined by measuring the dry matter consumed by the animal while grazing the cover crop. Since the farmer planted a mix of cover crops each season, the average price of category “other hay” was taken to estimate the cost of dry hay per ton. The price per Mg for 5 years from 2015-2019 was \$239.00, \$194.00, \$176.00, \$195.00, and \$202.00 (USDA’s National Agricultural Statistical Service, 2020) respectively, and the average price of \$201.28 Mg^{-1} was used for feed value estimation of grazed cover crops.

2.6 Statistical Analysis

The first experimental scenario was the grazed and ungrazed cover crop after corn silage and small grain harvest where the treatments were:

I. Recently grazed cover crop (previous day)
II. Cover crop grazed approximately 2 weeks earlier
III. Un-grazed cover crop

The collected data were analyzed as a randomized complete block design with the four farms (Franklin 1, Franklin 1, Adams 1, Adams 2) used as blocks in a factorial design with treatments being (1) Grazing treatment (Ungrazed, recently grazed and grazed 2-3 weeks earlier) and (2) Season (fall and spring). Fall season corresponded to the cover crops planted after small grain harvest, while the spring season were the cover crops planted after corn silage. Within each experimental unit, four sub-samples were collected. Data were entered in MS excel and imported into R studio for statistical analysis. To study the effect of management intensive grazing of cover crops in the spring and fall season, a standard least square analysis of variance (ANOVA) model was run. Prior to that, the data were tested for normality, (No transformation was performed on the data because it complied with all normalcy assumptions) and for a post hoc comparison of soil health indicators as affected by grazing and season, Tukey means separation tests were used. Effects were considered significant at $p < 0.05$. Analyses were conducted using R software version 4.0.3.

The second experimental scenario was double crop soybean/ full season soybean vs grazed cover crop mixtures after small grain harvest and the treatments were:

I. Double crop soybean/ full season soybean
II. Grazed cover crop

Given the constraints that arose from being research carried out in working farmers' fields, we had to fit the sampling process as per the farmer's flexibility. Following the restrictions arising from the farmer's management, the study with full season and double crop soybean and grazed cover crop was treated as a completely randomized design, with treatment and year as factors. Data were collected from two farms (Adams 1 and Franklin 1) and sampled within each field to get a measure of variability that was replicated four times. For this, we collected soil samples from four random spots within each field treatment and used them as pseudo-replicates. The soil type and slope under each treatment were similar and because of this, we used pseudo-replication as a viable approach to conduct the study on the farm (Chatterjee & Lal, 2009). We assumed that the spatial variability within the sampling area was autocorrelated.

To maintain uniformity and prevent anomalous field conditions, collection of soil samples was avoided from areas where animals seemed to aggregate (cattle camping zone), especially near the water source or shaded place, or excessively wet areas.

All the data were checked and treated for the assumption of normal distribution. Standard least square analysis of variance (ANOVA) models was run, and statistical significance was determined as $p < 0.05$ unless otherwise noted. Tukey mean separation tests were used for post hoc comparison of soil health indicators comparison between grazed cover crops and soybean.

CHAPTER 3. SOIL HEALTH EFFECTS OF MANAGEMENT INTENSIVE GRAZING OF COVER CROPS AND FORAGE VALUE

3.1 Results and Discussion

3.1.1 Soil Physical Properties

The physical properties of soil significantly influence a plant's capability to acquire water, nutrients, as well as oxygen. An increment in bulk density or penetration resistance indicates that soil has been compacted, a condition that can affect root development by limiting oxygen and nutrient diffusion through roots. Root penetration, as well as seed emergence, are facilitated by macroaggregate stability, which enables optimum water infiltration (Poffenbarger,2010).

Bulk density is a measure of soil compaction, a prime concern for farmers when it comes to grazing cover crops. Bulk density was not affected by MIGCC, did not vary by season, and no grazing treatment by season interaction was observed (Table 3.1). This shows that on aggregate, grazing did not negatively affect bulk density. Further, the bulk density value for all treatments and seasons was less than 1.30 g cm^{-3}, indicating a favorable porosity for root growth and soil function in these loamy soils (Arshad et al., 1997).

Similar results were reported in a four-year study carried out in northern Georgia, where Franzluebbers & Stuedemann (2008) found soil bulk density to be mostly unaffected by grazing of a cereal rye cover crop except for one year where bulk density for the depth of 0-5 cm increased from 1.02 to 1.08 g cm^{-3} due to grazing. For the same study, they found higher penetration resistance to a depth of 30 cm the first year under grazing compared to the un-grazed treatment but in the second year the difference in penetration resistance due to grazing was less, and in the third year the effect of grazing on penetration resistance dissipated. The effect of animal trampling on soil bulk density can be more pronounced when the field conditions are wet because with increased moisture percentage there is a decrease in soil strength. These conditions are more likely in spring in Pennsylvania. Bell et al.(2011) and Morris et al. (1998) studied a similar dimension where they found higher bulk density from grazing cover crops in early spring compared to grazing during the summer. However, in our study, the field were managed under long-term no-tillage with MIGCC implemented where animals were moved every day and back fencing was practiced so the soil was never exposed to animal impact for more than one day. This reduced animal trampling led soil compaction, and therefore, even in spring, no negative impact on soil compaction from grazing was observed.

Aggregate stability for 0-10 cm depth ranged from 83-87% (Table 3.1). MIGCC did not significantly affect aggregate stability and aggregate stability did not significantly vary between spring and fall seasons. Further aggregate stability was very high (>83%), showing the beneficial effects of long-term no-till used by all participating farmers. If grazing is managed and carefully implemented to avoid wet soil conditions, detrimental effects on aggregate stability can be avoided as observed in this research. Warren et al. (1986) did not observe reduced aggregate stability due to animal trampling in a permanent pasture in dry soil conditions, but under wet field conditions, the opposite was observed. Franzluebbers and Stuedemann (2008) reported that aggregate stability was not negatively affected by grazing in conventional and no-tillage systems, and occasionally increased due to grazing in no-tillage. Again, the use of management intensive grazing methods in our study would have helped to reduce the possibility for animal traffic to negatively impact aggregate stability.

Field saturated hydraulic conductivity ($Kf\ s$) was not significantly impacted by grazing, season, or their interaction (Table 3.1). Similarly, no significant difference for water infiltration among grazed and ungrazed cover crop was recorded in a study carried out by (Tobin et al., 2020) in South Dakota. Under a healthy soil ecosystem, a number of forces can come into play to alleviate compaction, such as the action of cover crop roots, the above and below-ground biodiversity, and soil freeze and thaw cycles. Therefore, under such conditions porosity can be maintained, and the effect of animal trampling on infiltration rate is minimal (Drewry et al., 2008). However, in our study there was not enough time (1 day) for soil compaction alleviation between UG and RG. The major factor explaining maintenance of high infiltration rates in grazed paddocks was therefore the resistance of the soil to potential impacts of animal traffic (probably due to the use of MIGCC in permanent no-till).

In summary, bulk density, aggregate stability, and field saturated hydraulic conductivity were not negatively affected by MIGCC in permanent no-till on the farms in this study. On the other hand, no improvement in these properties due to grazing was observed either.

Table 3.1 Soil physical properties (0-10cm) as influenced by season and cover crop grazing on four southcentral Pennsylvania farms for the year 2020 and 2021 after corn silage and small grain harvests.

	Bulk Density			**Wet Aggregate Stability**			**Field Saturated Hydraulic Conductivity (Kf s)**		
Season	UG	RG	LG	UG	RG	LG	UG	RG	LG
	——— g cm^{-3}——			——— %———			——— cm hr^{-1} ——		
Spring	1.19	1.18	1.21	83	84	83	27.82	11.21	17.13
Fall	1.19	1.28	1.17	88	88	87	20.28	15.18	18.96
	Analysis of Variance ($P > F$, significant at $P < 0.05$)								
Treatment		0.916			0.979			0.122	
Season		0.684			0.075			0.908	
Treatment*Season		0.554			0.972			0.620	

[1] UG Ungrazed cover crop; RG, Recently grazed cover crop; LG, cover crop grazed two weeks ago. No significant differences were observed.

3.1.2 Soil Biological Properties

No significant effect of grazing and seasons on soil CO_2 burst was recorded in this research (Table 3.2). Increased soil CO_2 burst is an indicator of increased microbial activity and aerobic microbial decomposition of soil organic matter which is one component of soil capacity to support crops and soil fauna (Gougoulias et al., 2014). The addition of manure and urine and possibly the trampling of cover crop residues into the soil upon grazing could stimulate microbial activity which could lead to increased CO_2 burst (Nair & Ngouajio, 2012). Especially with MIGCC, the below-ground biomass is not affected and in fact (due to proper resting period, frequent movement, right animal stocking density, grazing to a recommended height, sufficient residue, and manure distribution) the regrowth potential and the rooting depth of cover crops is expected to enhance (Andrae, 2014; McNaughton, 1979; Quigley & Anderson, 2014; Tracy & Zhang, 2008). This below-ground carbon input adds exudates and supports a variety of soil microorganisms by providing food to the microbial community which is essential for nutrient mineralization and for supporting soil structural stability (Hinsinger et al., 2009).Therefore, grazed cover crop fields could be expected to support greater microbial populations and exhibit higher CO_2 burst. However, this was not observed in this study.

Similarly, no effect of grazing, season, or their interaction on soil organic matter content was observed. In contrast to our results, several studies have recorded higher soil organic carbon (SOC) in grazed cover crop fields over ungrazed fields. A study by (Tracy & Zhang, 2008) found increasing soil organic carbon over time under winter grazed corn-oat pasture systems compared to ungrazed continuous corn systems. Tobin et al. (2020) found higher soil organic carbon for the ungrazed cover crop mix compared to the grazed cover crop mix in their study conducted in South Dakota. A collaborative project conducted in Iowa and Minnesota on 8 farms studied the effect of cover crop grazing in integrated livestock production on soil health and compared it to a production system with no cover grazing (control). They documented higher soil organic carbon for the grazed cover crop treatment among 7 of the farms (Filbert et al., 2021).

Soil organic carbon changes slowly, but we also measured permanganate oxidizable carbon, a measure of the active fraction of soil organic carbon that is thought to respond to management change more quickly than soil organic carbon (Culman et al., 2012). Permanganate oxidizable carbon was not affected by grazing across spring and fall seasons (Table 3.2). Though in our study we didn't record a positive effect of managed cover crop grazing on permanganate oxidizable carbon. Franzluebbers and Stuedemann (2015) reported a positive effect of grazing on soil microbial biomass C at a depth of 3 to 6 cm under a no-till system, but no effect was recorded for soil microbial biomass C under conventional till. Franzluebbers and Stuedemann (2008) also reported higher soil microbial biomass C under winter grazed cover crops compared to ungrazed winter cover crops, but no difference in total organic carbon was observed in grazing treatment under either conventional till or no-till. The authors reasoned that change in the carbon fraction could be from the addition of the new organic carbon from the cover crop biomass, root, roots exudates, shoot. This added biomass add soil organic carbon, providing food to the microbes and favoring growth of fungi with release of glomalin-related soil protein(Six et al., 1999). Further, the manure added to the field from animal grazing provides easily decomposable organic matter to microorganisms as compared to plant biomass from the ungrazed cover crop. Excreta contains a significant level of highly decomposable C and N compounds, which are easily accessible nutrients to soil micro-and macrobiota as well as plants, perhaps resulting in faster breakdown rates than plant residues (Bakker et al., 2004). Livestock ruminant digestion returns 75% of ingested N in urine and manure, providing immediate food to the microorganism as compared to plant biomass from the cover crop (Bakker et al., 2004; Kong et al., 2011; Zhu et al., 2020).

In summary, this research showed that MIGCC neither had a negative nor positive effect on soil physical and biological properties in permanent no-till. The lack of negative effects of grazing on these farms, some of which had poorly drained soils that would be highly sensitive to compaction, can probably be attributed to the limited exposure to animal foot traffic. Since the fields were never exposed to more than one day of animal trampling, with regular animal movement, and all farms used long-term no-till. The lack of positive effect on soil health may be attributed to the recent implementation of the practice on the farms; the farmers started implementing the practice at the beginning of our study.

Table 3.2 Soil biological properties (0-10 cm) as influenced by season and cover crop grazing treatment on four southcentral Pennsylvania farms for the year 2020 and 2021 after corn silage and small grain harvest.

	Soil CO_2 burst			**Soil organic matter content**			**Permanganate Oxidizable Carbon**		
Season	UG	RG	LG	UG	RG	LG	UG	RG	LG
	-mg of CO_2 kg^{-1} soil-			———g kg^{-1} ———			—— mg kg^{-1} ———		
Spring	718	819	882	41.5	43.2	36.5	653	650	754
Fall	1250	1046	848	37.1	32.8	34.7	695	732	818
	Analysis of Variance ($P > F$, significant at $P < 0.05$)								
Treatment	0.980			0.717			0.244		
Season	0.201			0.237			0.297		
Treatment*Season	0.474			0.746			0.965		

[2] UG, Ungrazed cover crop; RG, Recently grazed cover crop; LG, cover crop grazed two weeks ago. No significant effects were observed.

3.1.3 Biomass Yield of Cover Crop Species.

The balance in forage use for livestock feed and the amount of vegetative cover left standing for soil protection is key to enhancing the efficiency of management intensive grazing of cover crops. In simple terms, we can say the goal of management intensive grazing of cover crop was to “take half, leave half.” In practice, the farmers managed to leave more than half of the cover crop standing, except in spring 2021 on Franklin 1 when 53% was consumed. For all other grazing events, post-grazing forage dry matter exceeds total forage dry matter consumed (Table 3.3).

The cover crop after small grain harvest provided 1664-2111 kg ha^{-1} dry matter for livestock consumption per grazing throughout fall grazing for 2019, 2020, and 2021. For cover crops after the small grain harvest, it is possible to graze the cover crops multiple times, at least in the fall. Adams 1 yielded a total of 3746 kg ha^{-1} and 3365 kg ha^{-1} forage by grazing the cover crop twice in 2020 and 2021 respectively. Franklin 1 also grazed the field twice in the fall 2020, but due to time constraints, the yield could not be measured. Based on yields as other farms with multiple grazing events, it is reasonable to assume the total grazed yield is approximately double that measured in the one sampling. That results in an approximate total of 3888 kg ha^{-1} forage by grazing the cover crop twice in 2020. Franklin 1 grazed cover crop only once in fall 2021, with biomass yield of 1916 kg ha^{-1} forage dry matter.

A dry matter yield of 1425-2598 kg ha^{-1} per grazing was recorded for spring 2020 grazing of cover crops planted after corn silage harvest (Table 3.3). Franklin 1 was able to graze the cover crop twice in the spring which provided a total of 4349 kg ha^{-1} of forage dry matter to the livestock for the entire season before the cover crop was terminated for the next agronomic crop. Franklin 1 grazed a mix of triticale, hairy vetch, and crimson clover and Adams 1 grazed a mix of rye/vetch/brassica cover crop in spring 2021 (Table 3.3). Adams 2 grazed a rye cover crop planted after corn silage harvest in spring 2021. For spring 2021 grazing, 1129-2213 kg ha^{-1} forage dry matter yield was recorded per grazing. Adams 2 grazed the field twice in spring providing 3063 kg ha^{-1} dry matter forage to the livestock. Nutritional composition and palatability of the cover crop are higher in the early to mid-growth stages (Planisich et al., 2021), and if properly planned, farmers can graze the cover crops when the biomass is high while at the same time being careful to not let forage mature to the point that forage quality would be compromised. This strategy provides high quantity and quality forage for livestock grazing, thus offsetting the cost for expensive winter forage (Schomberg et al., 2014).

With respect to feed quality, neutral detergent fiber (NDF) and acid detergent fiber (ADF) content < 50% and < 35%, respectively, is considered as high-quality grass forage while more than >60% ADF is not ideal composition and suggests lower quality feed (Lepcha & Naumann, 2021). For spring 2020, 2021, and fall

2019, the NDF and ADF were below 50 % and 35%. For fall 2020 grazing the feed quality seemed to decline, especially for Franklin1 and Adams 1, as greater NDF and ADF content was recorded (65% and 36.3%) and (66.4%-67.4%and 42%-37.5%) respectively. One reason for the decrease in forage quality for franklin 1 could be grazing cover crops when they approached maturity. With maturity, there is an increase in hemicellulose, cellulose, and lignin content, and hence feed quality decreases (Lepcha & Naumann, 2021). For every second grazing, the NDF and ADF were slightly higher compared to first grazing suggesting not much decline in feed quality with second grazing of cover crops. The crude protein and total digestible nutrients content varied between 9.9-18.3 % and 63.4 -73.2%, respectively, for spring season while for fall 2020 it was between 9.3 to 20.6%, 55.5-63.9%, respectively. For overall fall grazing, Franklin 1 in 2021 recorded the highest crude protein (20.6%) and lowest neutral detergent fiber (38.3%) with total digestive nutrients as high as 58.6%. For spring grazing, the crude protein and total digestible nutrients content were recorded highest for Franklin 1 and Adams 2 in 2021 with as high as 18.2% and 17.4%, 71.2%, and 70.8% respectively. Higher protein content along with total digestive nutrients is usually associated with high-quality feed and improved production performance of livestock (Xia et al., 2018). Therefore, high-quality feed recorded in table 3.3 following a management intensive grazing system advocate for the cost-effectiveness of the cover crop grazing practice which can provide a very important justification for the farmer to invest in cover crops.

Table 3.3 Dry matter yield and forage quality of a variety of grazed cover crops planted after small grain (wheat) and corn silage harvest in 4 south-central Pennsylvania farms for fall 2019/20 and spring 2020/21.

	Dry matter yield of the grazed cover crops after small grain and corn silage harvest					**Plant component**			
Farm	**Total grazed area**	**Grazing period**	**Cover crop grazed**	**Post-grazing forage DM**	**Total forage DM consumed**	**Crude Protein**	**ADF**	**NDF**	**TDN**
	-ha-	-days-	—species—	—kg ha-1 —	—kg ha-1 —	__________ % _____________			
	Dry matter yield of the grazed cover crops after small grain harvest- Fall 2019								
Franklin 1	4.9	15	Ray’s crazy summer mix	2484	2111	10.5	27.7	46.4	64.4
	Dry matter yield of the grazed cover crops after corn silage harvest- spring 2020								
Franklin 1-1st grazing	1.6	14	Triticale	2791	2107	-	-	-	
Franklin 1-2nd grazing	1.6	13	Triticale	2631	2242	15	22.9	39.5	67.8
Franklin 2	2.8	6	Wheat	1534	1425	14.3	31.3	50.4	64
Adams 1	4.9	15	Wheat (after oats)	2207	2118	11	22.9	39.9	73.2
Adams 2	8.1	15	Annual ryegrass/crimson clover	6718	2598	9.9	34.7	49.3	63.4
	Dry matter yield of the grazed cover crops after small grain harvest- Fall 2020								
Adams 1-1st grazing	8.1	25	Millet	2122	1762	9.3	34.2	50.5	60.4

Adams 1-2nd grazing	8.1	24	Millet	2337	1984	12	32.7	55.6	63.9
Franklin 1-1st grazing	26.3	26	Ray’s crazy summer mix	2425	1944	9.6	36.3	65.1	60.6
Franklin 1-2nd grazing			Not sampled						
Dry matter yield of the grazed cover crops after corn silage harvest- spring 2021									
Franklin 1	1.6	18	Triticale/hairy vetch/crimson clover	1939	2213	18.3	26.6	42.1	71.2
Adams 1	8.1	17	Rye/vetch/brassica cover crop	3050	2205	12	25	44.7	70.5
Adams 2- 1st grazing	4.1	10	Ryegrass, crimson clover	2290	1129	17.4	26.5	37.2	70.8
Adams 2- 2nd grazing	4.1	10	Ryegrass, crimson clover	3810	1934	14.9	27.2	42.7	67.4
Dry matter yield of the grazed cover crops after small grain harvest- fall 2021									
Franklin 1	3.2	48	Millet, sunflower cowpea	2969	1916	20.6	30.6	38.3	58.6
Adams 1- 1st grazing	4.5	14	Sorghum Sudan	2338	1701	10.5	42	66.4	56.5
Adams 1- 2nd grazing	4.5	10	Sorghum Sudan	2178	1664	11.6	37.5	67.4	55.5

[3] Ray’s crazy summer mix: A warm-season mix of stress-tolerant summer cover crops like cowpea, sorghum-Sudan, pearl millet, radish, forage brassica, and sunflower. NDF: Neutral detergent fiber; ADF: Acid detergent fiber.

The economic value of the grazed cover crop was calculated using a value of \$201.32 $Mg^{-1}ha^{-1}$ the state average price of grass hay in Pennsylvania (USDA's National Agricultural Statistical Service, 2020). The upfront cost of grazing, comprised of water, fence, and labor cost, was considered. The added income was the economic value given to grazed forage dry matter. With this economic analysis, net revenue of from grazing cover crop ranged between \$82 to \$566 in spring 2020, \$172 to \$217 in spring 2021 and \$481 to \$359 cover crop in fall of 2019/2020/2021(Table 3.4). Looking across all the grazing season, we can say that the cost of labor was the determining factor for profit generation, while fence and water cost are one time investment and more over spread over years. The economic analysis took into account only the upfront cost and benefit to grazing cover crops while In a four year study conducted by Schomberg et al. (2014) in Georgia, the integrated cotton-cattle production system realized a return of \$260 ha^{-1} from grazing cereal rye. Likewise, where Franzluebbers and Stuedemann (2008) reported returns of \$255 ha^{-1} from grazing fall and spring residue of sorghum and corn residue and cereal rye cover crop respectively while the system without grazing resulted in a return of -\$47 ha^{-1}.

Table 3.4 Net revenue from cover crop grazing after corn silage and small grain harvest in 4 south-central Pennsylvania farms for fall 2019/20 and spring 2020/21.

Farm	Hay replacement value of cover crops	Labor cost	Water supply cost	Fence cost	Added income	Added cost	Net revenue
	$ ha^{-1}	$ ha^{-1}	$ ha^{-1}	$ ha^{-1}	$ ha^{-1}	$ ha^{-1}	$ ha^{-1}
Net revenue from grazed cover crops after small grain harvest- Fall 2019							
Franklin 1	425	100	26	103	425	229	196
Net revenue from grazed cover crops after corn silage harvest- Spring 2020							
Franklin 1	875	180	26	103	875	309	566
Franklin 2	287	60	30	115	287	205	82
Adams 1	426	100	51	107	426	258	168
Adams 2	523	150	39	160	523	349	174
Net revenue from grazed cover crops after small grain harvest- Fall 2020							
Adams 1	754	327	51	107	754	485	269
Franklin 1	783	173	26	103	783	302	481
Net revenue from grazed cover crops after corn silage harvest- Spring 2021							
Franklin 1	445	120	26	103	445	249	196
Adams 1	444	113	51	107	232	271	173
Adams 2	616	200	39	160	616	399	217
Net revenue from grazed cover crops after small grain harvest- fall 2021							
Franklin 1	386	160	26	103	386	289	97
Adams 1	677	160	51	107	677	318	359

3.2 Conclusion

Under management intensive grazing of cover crops a number of factors, cost of infrastructure, animal, labor, soil and cover crop management, come into play to determine the profitability of the practice and to evaluate the effect on soil health. The study found that soil physical and biological properties were not significantly affected by management intensive grazing of cover crops. From the production and economic perspective, the labor cost was one of the determining factors for profit generation from grazing cover crops. This emphasizes the importance of effective grazing management in order to get the most out of grazing cover crops. With proper management, aim to take half cover crop biomass for animal consumption and leave half for soil protection, farmers were able to provide up to 1944-3746 kg ha^{-1} forage dry matter in fall 2019/20. While in fall 2021 management intensive grazing of cover crops provided 1916-3365 kg ha^{-1} forage dry matter, 1425-4349 kg ha^{-1} forage dry matter in spring 2020, and 1154-3063 kg ha^{-1} forage dry matter in spring 2021. Net revenue calculated using upfront cost from grazing cover crops ranged between \$82 to \$566 in spring 2020/2021 and \$481 to \$359 in fall 2019/2020/2021. Taking only upfront cost, management intensive grazing spoke for profitability of the practice without accounting for animal gain and the soil health benefit expected from cover crops on long terms. Therefore, we conclude that with proper management livestock grazing of cover crops can create a win-win situation for the farmers that generates additional income for the farmers without detrimental effects to the soil and therefore to following crops. Beneficial effects on soil health of grazing were not found in our study and may be due to the relatively recent implementation of management intensive grazing cover cops on these farms.

CHAPTER 4. SOIL HEALTH AND PROFITABILITY IMPACTS OF MANAGEMENT INTENSIVE GRAZING OF COVER CROPS VS DOUBLE CROPPED SOYBEANS AFTER SMALL GRAINS

4.1 Result and Discussion

4.1.1 Soil physical properties

In Franklin 1, the effect of year on bulk density was significant but the effect of treatment and interaction between treatment and year on bulk density was not significant (Table 4.1). For both treatments, grazed cover crop and soybean, bulk density in 2019 was considerably greater than in 2020 and 2021. In the study reduced bulk density over years is suggestive of improved soil structure with time as both fields were managed under continuous no till systems. Under long term no till system a number of practices such as crop rotation, cover crops or the natural cycle of annual freeze/thaw and wet/dry improve porosity (Liebig et al., 2012). Decreased bulk density relates to increased soil porosity, alleviating compaction which facilitates better water infiltration and root growth (Bell et al., 2011). Especially for grazed cover crop fields, it could either be from the herbivory action, addition of manure from the animal, residue decomposition, and subsequent action of micro-organisms (Poffenbarger, 2010).

Wet aggregate stability in Franklin 1 for 0-10 cm depth was high in all cases, ranging from 85%-94% (Table 4.1). The effect of year and treatment was not significant on aggregate stability while significant interaction was revealed between treatment and year. Greater aggregate stability means the soil is less prone to soil degradation by wind, water, or animal action. Higher soil structural stability is of great significance under management intensive grazing since greater is the resistance of soil to the action of animal trampling under such soil (Franzluebbers & Stuedemann, 2008). Soil structural stability is generally found to increase with increased microbial activity and soil organic matter content (Liu et al., 2019) The added manure and crop residue left after cover crop grazing was expected to improve soil microbial activity which in turn would help to improve soil's structural stability, The study showed greatest aggregate stability in 2021 (93%) compared to 2019 and 2020 (85%) in grazed cover crop fields,, while no difference was revealed for soybean fields. This could be due to improving soil structural stability from increasing soil microbial activity, below-ground growth in soil microflora and fauna with the addition of crop residue and animal manure from management intensive grazing and no till management system Franzluebbers & Stuedemann (2008). A study conducted in Georgia focused on evaluation of soil health under grazing management in a no till system found greater aggregate stability in grazed cover crops field after several years (Franzluebbers & Stuedemann, 2008).

The effect of treatment and year was significant on field saturated hydraulic conductivity for Franklin 1 (Table 4.1), while there was no treatment x year interaction. Higher field saturated hydraulic conductivity was revealed for the grazed cover crop compared to full season soybean in 2019 and double crop soybean in 2020 and 2021. The cover crop residue left after grazing may have protected the soil against the beating action of rain by dissipating its impact energy that reduced the detachment of soil particles and prevented soil seal and crust formation. Furthermore, grazing animals may have boosted soil structural stability and field saturated hydraulic conductivity by stimulating biological activity and the mat-like root structure serving as a geotextile to soak up animal tramping stress. The crop residue of soybeans is rich in N and has a low C: N ratio thus quickly decomposing, leaving the soil exposed to the impact of water droplets, soil crusting, runoff, and reducing soil hydraulic conductivity (Gezahegn et al., 2019).

Table 4.1 Soil physical properties (0-10cm) as influenced by year and treatments on Franklin 1 evaluated and compared between full season soybean and grazed cover crop in 2019 and double crop soybean and grazed cover crop in 2020 and 2021.

	Bulk Density		**Wet Aggregate Stability**		**Field saturated hydraulic conductivity (Kf s)**	
Year	GCC	SOY	GCC	SOY	GCC	SOY
	—— g cm^{-3}———		—— %——		— cm/hour^{-1} —	
2019	1.174 ^{b}	1.193 ^{b}	85 ^{a}	94 ^{b}	69.23 ^{d}	31.05 ^{bc}
2020	0.998 ^{a}	1.036 ^{a}	85 ^{a}	89 ^{ab}	36.38 ^{c}	14.9 ^{ab}
2021	0.955 ^{a}	1.036 ^{a}	93 ^{b}	87 ^{ab}	28.64 ^{bc}	5.08 ^{a}
Analysis of Variance (P > F, significant at P < 0.05)						
Treatment	0.05453		0.2316		0.0000	
Year	0.0000		0.2853		0.0000	
Treatment* Year	0.5459		0.0004		0.1105	

[4] GCC, Cover crop grazed a month ago; SOY, Soybean. Mean values followed by the same letters between treatments and across years are not significantly different.

For Adams 1, there was no effect of treatment, year, and treatment x year interaction on bulk density and field saturated hydraulic conductivity (Kfs). However, for Adams 1, 12-13% greater aggregate stability was revealed for soil under grazed cover crops compared to double crop soybean in 2020 and 2021 which could be due to improving soil biological activity and subsequent structural stability of soil from the addition of crop residue and animal manure (Table 4.2). Further, our finding is supported with research conducted by Alberts & Wendt (1985) who found higher soil loss under soybean plants with alteration in size and structural stability of soil aggregates thereby reducing the overall aggregate stability. Similarly Franzluebbers & Stuedemann (2008) found increasing aggregate stability after years of grazed cover crop managed under no till system.

Table 4.2 Soil physical properties (0-10cm) as influenced by year and treatments on Adams 1 evaluated and compared between double crop soybean and grazed cover crop in 2020 and 2021.

	Bulk Density		**Wet Aggregate Stability**		**Field saturated hydraulic conductivity (Kfs)**	
Year	GCC	SOY	GCC	SOY	GCC	SOY
	—— $g\ cm^{-3}$ ——		—— % ——		—— $cm/hour^{-1}$ ——	
2020	0.928	0.971	85.2 ^{bc}	72.4 ^{a}	12.96	14.7
2021	0.948	1.036	88.4 ^{c}	76.3 ^{ab}	15.32	8.54
	Analysis of Variance (P > F, significant at $P < 0.05$)					
Treatment	0.1221		0.0003		0.5835	
Year	0.3003		0.1778		0.6786	
Treatment x Year	0.5788		0.8932		0.3633	

[5]GCC, Cover crop grazed a month ago; SOY, Soybean. Mean values followed by the same letters between treatments and across years are not significantly different.

4.1.2 Soil biological properties

The carbon in above and below ground cover crop biomass and manure is expected to increase the activity of microbial soil organisms in grazed cover crop fields (Nair & Ngouajio, 2012) compared to limited quick decomposing biomass from soybeans. However, this effect was not observed in the case of Franklin 1, as no significant effect on soil carbon dioxide burst was revealed from management intensive grazing of cover crops of soybeans. Soil carbon dioxide is the indicator of change in carbon dioxide (CO_2) concentration over a given period within a defined volume of soil in response to soil microbial activity (Joshi Gyawali et al., 2019). For soil organic matter content, the effect of treatment and year was significant while the interaction between treatment and year was not significant (Table 4.3). In 2019, the soil of the grazed cover crop (51.7 $g\ kg^{-1}$) had significantly higher soil organic matter content than that under full season soybean (41.8 $g\ kg^{-1}$), while for 2020 there was no difference in soil organic matter content between grazed cover crop and double crop soybean. For

2021 we saw higher soil organic matter content under grazed cover crop (45.6 g kg^{-1}) compared to double crop soybean (35.3 g kg^{-1}). Though we saw higher organic matter content for grazed cover crops compared to soybean fields in 2019 and 2021, soil organic matter content is a property subject to long term change that happens in response to soil biological, chemical, and physical changes with soil improving management practices over years and may therefore have been an effect of past management differences between paddocks (Bergtold et al., 2019).

The effect of treatment, year, and their interaction on permanganate oxidizable carbon at Adams 1 was significant. In comparison to full season soybean in 2019 and double crop soybean in 2021, the grazed cover crop showed greater Permanganate Oxidizable Carbon. This increase in permanganate oxidizable carbon could be from a change in the carbon fraction resulting from the addition of the new organic carbon source (cover crop biomass: root, roots exudates, shoot). This added organic carbon plays a crucial role in providing food to the microbes and is responsible for growth in their population (Six et al., 1999). Further, under management intensive grazing of cover crops, the field has manure and urine added from animal grazing which is an easily decomposable organic matter as it has already undergone ruminant gut fragmentation and digestion. Excreta contains a significant level of highly decomposable C and N compounds (narrow C: N ration), which provide easily accessible nutrients to soil micro-and macrobiota as well as plants, perhaps resulting in faster breakdown rates than plant residues (Bakker et al., 2004). Livestock ruminant digestion returns in 75% of ingested N, providing immediate food to the microorganism as compared to the plant biomass from the cover crop (Bakker et al., 2004; Kong et al., 2011; Zhu et al., 2020).

Table 4.3 Soil biological properties (0-10cm) as influenced by year and treatments on Franklin 1 evaluated and compared between full season soybean and grazed cover crop in 2019 and double crop soybean and grazed cover crop in 2020 and 2021.

	Soil CO_2 burst		**Soil organic matter content**		**Permanganate Oxidizable Carbon**	
Year	GCC	SOY	GCC	SOY	GCC	SOY
	-mg of CO_2 kg^{-1} soil-		———g kg^{-1} ———		—— mg kg^{-1} ———	
2019	908	958	5.17^{c}	4.18^{ab}	964^{d}	773^{c}
2020	1032	727	4.21^{ab}	4.09^{ab}	602^{abc}	584^{ab}
2021	1141	544	4.56^{bc}	3.53^{a}	690^{bc}	468^{a}
	Analysis of Variance ($P > F$, significant at $P < 0.05$)					
Treatment	0.0806		0.0011		0.0007	
Year	0.8913		0.0284		0.0000	
Treatment*Year	0.2399		0.0759		0.0359	

[6]GCC, Cover crops grazed a month earlier, SOY, Soybean. Mean values followed by the same letters between treatments and across years are not significantly different.

Under management intensive grazing of cover crops for Adams 1, the effect of treatment, year, and treatment x year interaction was not significant for soil CO_2 burst and soil organic matter content (Table 4.4) across 2020 and 2021. In 2021, however, we found that grazed cover crops had higher permanganate oxidizable carbon than double crop soybean. This could be attributed to an increase in readily available carbon to soil microbial population resulting from the herbivory addition that adds manure, urine, saliva (easily decomposable organic matter) and also from addition high cover crop biomass as compared to that from soybean plants (Bakker et al., 2004; Kong et al., 2011; Zhu et al., 2020).

Table 4.4 Soil biological properties (0-10cm) as influenced by year and treatments on Adams 1 evaluated and compared between double crop soybean and grazed cover crop in 2020 and 2021.

	Soil CO_2 burst		**Soil organic matter content**		**Permanganate Oxidizable Carbon**	
Year	GCC	SOY	GCC	SOY	GCC	SOY
	-mg of CO_2 kg^{-1} soil-		———g kg^{-1} ———		—— mg kg^{-1} ———	
2020	1139	1376	3.6	3.44	550 ^{a}	513 ^{a}
2021	1668	1091	3.93	3.53	678 ^{b}	452 ^{a}
	Analysis of Variance ($P > F$, significant at $P < 0.05$)					
Treatment	0.6209		0.0606		0.0050	
	0.7223		0.1450		0.4103	
	0.2415		0.3702		0.0083	

[7]GCC, Cover crop grazed a month ago; SOY, Soybean. Mean values followed by the same letters between treatments and across years are not significantly different.

4.1.3 Partial Budget Analysis

Only two farms i.e, Adams 1 and Franklin 1 planted double crop soybean in the fall. Partial budget analysis was calculated for change in management practice comprising of switching from establishment of double crop soybean to management intensive grazing of cover crops. For this change in management practice, negative as well as a positive change in profit was studied.

Due to early frost in the fall of 2020, double crop soybean was a failure at Adams-1 farm and subsequently, the yield was zero. Because of this, a change in profit as high as \$523.13 ha^{-1} was revealed when the partial budget analysis was calculated for Adams1 in fall 2020 (Table 4.5). While, in 2021 the farmer harvested wheat for forage and was able to plant double crop soybean as early as May 19, hence recording a good yield (3969 kg ha^{1}). The partial budget analysis calculated for Adams 1 in fall 2021 revealed a change in profit of \$103.38 with a switch in management practice from double crop soybean to management intensive grazing of cover crops. However, for Franklin1 fall 2020, the change in profit was -\$250.40

ha^{-1} and -\$93.28 ha^{-1} in 2020 and 2021 (Table 4.6). Good performance of the soybean crop in 2020 and 2021 accounted for negative return with change in management practice from double crop soybean to management intensive grazing of cover crops for Franklin 1. Change in profit was positive for Adams 1 compared to Franklin 1 for 2020 and 2021 as Adams 1 was able to graze the cover crop twice in the fall with a cumulative yield of 3063 kg ha^{-1} and 3365 kg ha^{-1} in 2020 and 2021 respectively. While Franklin 1 grazed it once providing livestock with 2213 kg ha^{-1} and 1916 kg ha^{-1} forage in 2020 and 2021. Further double crop soybean was a complete failure for Adams 1 in 2020. Immediate benefits from the cover crop grazing are attributed to the reduction in forage cost. Timeline of the cover crop, cropping calendar, and the availability of forage for grazing should be considered to maximize the profit from cover crop grazing.

The economic return obtained from the research indicates cover crop grazing can generate income that can cover or even exceed the cost associated with the establishment of cover crops along with the cost incurred in grazing cover crops. A similar result was indicated by Schomberg et al (2014) in four-year research conducted in Georgia under an integrated cotton-cattle production system where a profit of \$260 ha^{-1} was showed with grazed cereal rye. Further, Franzluebbers & Stuedemann (2007) observed net returns exceeding the variable cost of \$302 ha^{-1} through grazing fall and spring sorghum residue, maize residue, and cereal rye cover crop, correspondingly, whereas the net return without grazing was -\$63 ha^{-1}. In a study, even though the cover crop was not available for grazing throughout the season but the cost of hay and land use for pasture was reduced with late fall and early spring grazing (Morris et al., 1998).

The partial budget analysis only took into account the upfront direct cost. It didn’t take into account any positive soil health benefits that are expected from cover crops, especially in the long run the benefits from the integration of cover crop with grazing is expected to increase given the added organic matter, improved water holding capacity, a structural improvement from increased soil organic matter content, which might reduce the need for chemical fertilizer and pesticide. Although an economic return was seen quickly with grazing the maximum revenue is expected to accrue through several years as the soil improves and the farmer gains expertise integrating livestock and cover crops into their system overall (Bergtold et al., 2019).

Table 4.5 Partial budget analysis for Adams 1 and Franklin 1 calculated with change in management practice from double crop soybean to management intensive grazing of cover crop in fall 2020.

Adams 1 2020				**Franklin 1 2020**			
Additional cost	**$\$\ \mathrm{ha}^{-1}$**	**Additional income**	**$\$\ \mathrm{ha}^{-1}$**	**Additional cost**	**$\$\ \mathrm{ha}^{-1}$**	**Additional income**	**$\$\ \mathrm{ha}^{-1}$**
Seed cost	$71.41	Forage feed value	$753.95	Seed cost	$123.55	Forage feed value	$391.16
Planting cost	$37.07			Planting cost	$37.07		
Termination cost	$0.00			Termination cost	$0.00		
Fence cost	$107			Fence cost	$103		
Water supply cost	$51			Water supply cost	$26		
Labor cost	$327			Labor cost	$173		
Total additional cost	$593	Total additional income	$753.95	Total additional cost	$462.62		$391.16
Reduced income		Reduced cost		Reduced income		Reduced cost	
Soybean yield	$0.00	Seed cost (Soybean)	$195.21	Soybean yield	$494.20	Seed cost (Soybean)	$123.55
		Planting cost	$37.07			Planting cost	$37.07
		Chemical/application cost	$130.38			Chemical/application cost	$55.80
		Harvesting cost				Harvesting cost	$98.84
Total reduced cost	$0.00	Total reduced cost	$362.65	Total reduced income	$494.20	Total reduced cost	$315.26
Total additional cost and reduced income	$593	Total additional income and reduced cost	$1116.6	Total additional cost and reduced income	$956.82	Total additional income and reduced cost	$706.42
		Minus				Minus	
		Change in profit	$523.13			Change in profit	-$250.4

[8] Fence and water cost was calculated by spreading the one time investment over 10 and 5 years respectively. Labor cost was calculated on per days basis multiplied over season.

Table 4.0.6 Partial budget analysis for Adams 1 and Franklin 1 calculated with change in management practice from double crop soybean to management intensive grazing of cover crop in fall 2021.

Adams 1 2021				**Franklin 1 2021**			
Additional cost	**$ ha^{-1}**	**Additional income**	**$ ha^{-1}**	**Additional cost**	**$ ha^{-1}**	**Additional income**	**$ ha^{-1}**
Seed cost	$130.72	Forage feed value	$677.31	Seed cost	$123.55	Forage feed value	$385.66
Planting cost	$37.07			Planting cost	$86.49		
Termination cost	$0.00			Termination cost	$0.00		
Fence cost	$107			Fence cost	$103		
Water supply cost	$51	105.12		Water supply cost	$26		
Labor cost	$160			Labor cost	$160		
Total additional cost	$485.79	Total additional income	$677.31	Total additional cost	$499.04	Total additional income	$385.66
Reduced income		Reduced cost		Reduced income		Reduced cost	
Income from Soybean yield	$542.08	Seed cost (Soybean)	$166.80	Income from Soybean yield	$385.65	Seed cost (Soybean)	$111.20
		Planting cost	$37.07			Planting cost	$86.49
		Chemical/application cost	$138.38			Chemical/application cost	$59.80
		Harvesting cost	$111.69			Harvesting cost	$148.26
Total reduced income	$542.08	Total reduced cost	$453.93	Total reduced income	$385.65	Total reduced cost	$405.75
Total additional cost and reduced income	$1027.87	Total additional income and reduced cost	$1131.24	Total additional cost and reduced income	$884.69	Total additional income and reduced cost	$791.41
		Minus				Minus	
		Change in profit	$103.38			Change in profit	-$93.28

[9] Fence and water cost was calculated by spreading the one time investment over 10 and 5 years respectively. Labor cost was calculated on per days basis multiplied over season.

4.2 Conclusion

Under management intensive grazing of cover crops, Franklin 1 revealed higher field saturated hydraulic conductivity for grazed cover crops compared to full season soybean in 2019 and double crop soybean in 2020 and 2021. Likewise, higher organic matter content was revealed for grazed cover crops than full season soybean in 2019 and double crop soybean in 2021. For aggregate stability, no difference was observed among treatments in 2020 and 2021 and but full season soybean in 2019 showed greater aggregate stability than grazed cover crops. For bulk density, the effect of treatment was not significant while a significant difference was revealed across years where the bulk density was showed to decrease in 2020 and 2021 compared to 2019 for both the treatment, grazed cover crop and soybean. Grazed cover crops revealed higher permanganate oxidizable carbon than full season soybean in 2019 and double crop soybean in 2021 while no difference was showed among treatments in 2020. The effect of treatment, year, and their interaction was not significant on soil CO_2 burst. For Adams 1 no significant difference was revealed among treatment for bulk density, field saturated hydraulic conductivity, soil CO_2 burst, and soil organic matter content. In comparison to double crop soybean, Adams 1 found that soil under grazed cover crops had more permanganate oxidizable carbon in 2021 and improved structural stability in 2020 and 2021. This could be due to improving soil biological activity and subsequent structural stability of soil from the addition of crop residue and animal manure.

Partial budget analysis calculated for change in management practice from double crop soybean to management intensive grazing of cover crops revealed a net positive return of \$523.13 ha^{-1} to \$103.38 ha^{-1} for Adams 1 in 2020 and 2021. Due to early frost, Adams 1 failed to harvest any yield from the double crop soybean fields in 2020 while grazing cover crop twice in the fall provided 4459 kg ha^{-1} and 3365 kg ha^{-1} in 2020 and 2021 forage. Therefore, in 2020 and 2021 grazed cover crops were more profitable than double crop soybean and in addition presented less risk for the farmer. However, for Franklin 1, with a change in management practice from double crop soybean to grazed cover crop in 2020 and 2021 the change in revenue was -\$250.40 ha^{-1} and -\$93.28 ha^{-1}. Grazing cover crop doesn’t seem to be profitable when regular performance and yield is obtained from double crop soybean. However, when the weather conditions are extreme (early frost, extended drought), grazing cover crop is more resilient and less risky practice than double crop soybean. Thus, the research suggests management intensive grazing of cover crops could result in better soil health and provide the farmers a more resilient source of income compared to double crop soybean.

4.3 International Component of the Research (Context of Nepal)

Grazing has been proven to have a significant impact on species composition, plant height, standing biomass, dead biomass, and sward structure, among other things (Vera, 1991). In alpine locations, especially in developing nations like Nepal, grazing in pasture management is a contentious issue. The Nepalese economy is agriculturally based, with around 67 % working in agriculture, which is a typical mix of crops, livestock, and forests in an integrated mixed farming method. Livestock provides around 31% of the country's overall GDP, with the hills accounting for the most - 53%, followed by the terai - 38%, and the mountains accounting for the least - 9% (Krupnik et al., 2021). This is one of the reasons for the importance of emphasizing livestock-based development possibilities on mountain people, who rely heavily on livestock for survival. Most of the grazing land in Nepal is poorly managed, with poor soil health and vegetation because of overgrazing. The impacts of grazing on species variety are still being investigated (Perelman et al., 1997) and both moderate and intensive grazing have been cited as sources of enhanced diversity (Bhattarai et al., 2004). Grasslands cover roughly 1.7 million hectares of Nepal's total geographic area of 14.7 million hectares; they are dominated by herbaceous plants and grazed by ruminants. The two sections known as the Middle Hills and Mountains include 98% grasslands (Thapa et al., 2016). Therefore, given this vast area under grazing, implementation of managed grazing like management intensive grazing could be a potential practice to prevent deterioration of soil health, very common in the context of Nepal, while increasing crop and livestock productivity.

4.4 References

Abdalla, M., Hastings, A., Cheng, K., Yue, Q., Chadwick, D., Espenberg, M., Truu, J., Rees, R. M., & Smith, P. (2019). A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. *Global Change Biology*, *25*(8), 2530–2543. https://doi.org/10.1111/gcb.14644

Adetunji, A. T., Ncube, B., Mulidzi, R., & Lewu, F. B. (2020). Management impact and benefit of cover crops on soil quality: A review. *Soil and Tillage Research, 204*, 104717. https://doi.org/10.1016/j.still.2020.104717

Alberts, E. E., & Wendt, R. C. (1985). Influence of Soybean and Corn Cropping on Soil Aggregate Size and Stability. *Soil Science Society of America Journal*, *49*(6), 1534–1537. https://doi.org/10.2136/sssaj1985.03615995004900060040x

Andrae, J. (2014). *Rotational Grazing Benefits and Specific Methods*. *41*(Table 1), 104–108.

Arshad, M. A. (Charlie), Lowery, B., & Grossman, B. (1997). Physical Tests for Monitoring Soil Quality. In *Methods for Assessing Soil Quality* (pp. 123–141). John Wiley & Sons, Ltd. https://doi.org/10.2136/sssaspecpub49.c7

Bakker, E. S., Olff, H., Boekhoff, M., Gleichman, J. M., & Berendse, F. (2004). Impact of herbivores on nitrogen cycling: Contrasting effects of small and large species. *Oecologia*, *138*(1), 91–101. https://doi.org/10.1007/s00442-003-1402-5

Balkcom, K., Schomberg, H., Reeves, W., & Clark, A. (2007). *Managing Cover Crops Profitably* (3rd ed.). SARE. https://www.sare.org/publications/managing-cover-crops-profitably/managing-cover-crops-in-conservation-tillage-systems/

Barnwal, P., Devika, S., Singh, S., Behera, T., Chourasia, A., Pramanick, B., Meena, V. S., & Rakshit, A. (2021). Chapter 3—Soil fertility management in organic farming. In V. S. Meena, S. K. Meena, A. Rakshit, J. Stanley, & C. Srinivasarao (Eds.), *Advances in Organic Farming* (pp. 39–46). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-822358-1.00016-X

Bell, L. W., Kirkegaard, J. A., Swan, A., Hunt, J. R., Huth, N. I., & Fettell, N. A. (2011). Impacts of soil damage by grazing livestock on crop productivity. *Soil and Tillage Research*, *113*(1), 19–29. https://doi.org/10.1016/j.still.2011.02.003

Berger, A. (2017). *Annual Forages and Windrow Grazing as an Alternative to Cash Grain Crops*. CropWatch. https://cropwatch.unl.edu/2017/annual-forages-and-windrow-grazing-alternative-cash-grain-crops

Bergtold, J. S., Ramsey, S., Maddy, L., & Williams, J. R. (2019). A review of economic considerations for cover crops as a conservation practice. *Renewable Agriculture and Food Systems*, *34*(1), 62–76. https://doi.org/10.1017/S1742170517000278

Betteridge, K., Mackay, A. D., Shepherd, T. G., Barker, D. J., Budding, P. J., Devantier, B. P., & Costall, D. A. (1999). Effect of cattle and sheep treading on surface configuration of a sedimentary hill soil. *Australian Journal of Soil Research*, *37*(4), 743–760. https://doi.org/10.1071/sr97014

Bhattarai, K. R., Vetaas, O. R., & Grytnes, J. A. (2004). Relationship between plant species richness and biomass in an arid sub-alpine grassland of the central Himalayas, Nepal. *Folia Geobotanica*, *39*(1), 57–71. https://doi.org/10.1007/BF02803264

Bilotta, G. S., Brazier, R. E., & Haygarth, P. M. (2007). The Impacts of Grazing Animals on the Quality of Soils, Vegetation, and Surface Waters in Intensively

Managed Grasslands. In *Advances in Agronomy* (Vol. 94). Elsevier Masson SAS. https://doi.org/10.1016/S0065-2113(06)94006-1

Blanco-Canqui, H., Drewnoski, M. E., MacDonald, J. C., Redfearn, D. D., Parsons, J., Lesoing, G. W., & Williams, T. (2020). Does cover crop grazing damage soils and reduce crop yields? *Agrosystems, Geosciences & Environment*, *3*(1), 1–11. https://doi.org/10.1002/agg2.20102

Blanco-Canqui, H., Shaver, T. M., Lindquist, J. L., Shapiro, C. A., Elmore, R. W., Francis, C. A., & Hergert, G. W. (2015). Cover Crops and Ecosystem Services: Insights from Studies in Temperate Soils. *Agronomy Journal*, *107*(6), 2449–2474. https://doi.org/10.2134/agronj15.0086

Brink, L., & McCarl, B. (1978). The Tradeoff between Expected Return and Risk Among Cornbelt Farmers. *American Journal of Agricultural Economics*, *60*(2), 259–263. https://doi.org/10.2307/1240057

Buyer, J. S., Teasdale, J. R., Roberts, D. P., Zasada, I. A., & Maul, J. E. (2010). Factors affecting soil microbial community structure in tomato cropping systems. *Soil Biology and Biochemistry*, *42*(5), 831–841. https://doi.org/10.1016/j.soilbio.2010.01.020

Cary, J. W., & Wilkinson, R. L. (1997). Perceived profitability and farmers' conservation behaviour. *Journal of Agricultural Economics*, *48*(1), 13–21. https://doi.org/10.1111/j.1477-9552.1997.tb01127.x

Chanasyk, D. S., & Naeth, M. A. (1995). Grazing impacts on bulk density and soil strength in the foothills fescue grasslands of Alberta, Canada. *Canadian Journal of Soil Science*, *75*(4), 551–557. https://doi.org/10.4141/cjss95-078

Chatterjee, A., & Lal, R. (2009). On farm assessment of tillage impact on soil carbon and associated soil quality parameters. *Soil and Tillage Research*, *104*(2), 270–277. https://doi.org/10.1016/j.still.2009.03.006

Clark, A. (2007). *Managing cover crops profitably*. SARE.

Clark, A. (2017). *National Cover Crop Surveys*. SARE. https://www.sare.org/publications/cover-crops/national-cover-crop-surveys/

Clark, J. T., Russell, J. R., Karlen, D. L., Singleton, P. L., Busby, W. D., & Peterson, B. C. (2004). Soil surface property and soybean yield response to corn stover grazing. *Agronomy Journal*, *96*(5), 1364–1371. https://doi.org/10.2134/agronj2004.1364

Conservation Technology Information Center. (2020, August). *ANNUAL REPORT 2019-2020 National Cover Crop Survey* [Https://www.sare.org/wp-content/uploads/2019-2020-National-Cover-Crop-Survey.pdf]. SARE. https://www.sare.org/news/2020-cover-crop-survey-report/

Cornelisse, S. (2017). *Partial Budgeting for Agricultural Businesses*. Penn State Extension. https://extension.psu.edu/partial-budgeting-for-agricultural-businesses

Costa, N. R., Andreotti, M., Mascarenhas Lopes, K. S., Yokobatake, K. L., Ferreira, J. P., Pariz, C. M., Dos Batista Bonini, C. S., & Longhini, E. V. Z. (2015). Atributos do solo e acúmulo de carbono na integração lavoura-pecuária em sistema plantio direto. *Revista Brasileira de Ciencia Do Solo*, *39*(3), 852–863. https://doi.org/10.1590/01000683rbcs20140269

Culman, S. W., Snapp, S. S., Freeman, M. A., Schipanski, M. E., Beniston, J., Lal, R., Drinkwater, L. E., Franzluebbers, A. J., Glover, J. D., Grandy, A. S., Lee, J., Six, J., Maul, J. E., Mirksy, S. B., Spargo, J. T., & Wander, M. M. (2012). Permanganate Oxidizable Carbon Reflects a Processed Soil Fraction that is

Sensitive to Management. *Soil Science Society of America Journal*, *76*(2), 494–504. https://doi.org/10.2136/sssaj2011.0286

Dabney, S. M., Delgado, J. A., & Reeves, D. W. (2001). Using Winter Cover Crops to Improve Soil and Water Quality. *Communications in Soil Science and Plant Analysis*, *32*(7–8), 1221–1250. https://doi.org/10.1081/CSS-100104110

Drewry, J. J. (2006). Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: A review. *Agriculture, Ecosystems and Environment*, *114*(2–4), 159–169. https://doi.org/10.1016/j.agee.2005.11.028

Drewry, J. J., Cameron, K. C., & Buchan, G. D. (2008). Pasture yield and soil physical property responses to soil compaction from treading and grazing—A review. *Australian Journal of Soil Research*, *46*(3), 237–256. https://doi.org/10.1071/SR07125

Eckert, D., & Sims, J. T. (2011). *Chapter 3 Recommended Soil pH and Lime Requirement Tests*. http://citeseerx.ist.psu.edu/viewdoc/citations;jsessionid=B28B7C0571E3A7B936C5A1495DB28A47?doi=10.1.1.226.4091

Economic and Soil Health Impact of Grazing Cover Crops, 2018-2019. (2020). Practical Farmers of Iowa. https://practicalfarmers.org/research/economic-and-soil-health-impact-of-grazing-cover-crops-2018-2019/

Ericson, U. (2009). *Grazing in Practice—Prescribed Grazing: Management Methods—Managing Invasive Plants*. Managing Invasive Plants. https://www.fws.gov/invasives/stafftrainingmodule/methods/grazing/practice.html

Fernández, P. L., Alvarez, C. R., Taboada, M. A., Fernández, P. L., Alvarez, C. R., & Taboada, M. A. (2011). Assessment of topsoil properties in integrated crop–livestock and continuous cropping systems under zero tillage. *Soil Research*, *49*(2), 143–151. https://doi.org/10.1071/SR10086

Filbert, M., Degner, W., Frederick, B., Kennedy, Z., & Smith, S. (2021). *Economic and Soil Health Impact of Grazing Cover Crops in Cow-Calf Operations*. Practical Farmers of Iowa. https://practicalfarmers.org/research/economic-and-soil-health-impact-of-grazing-cover-crops-in-cow-calf-operations/

Francis, G. S., Bartley, K. M., & Tabley, F. J. (1998). The effect of winter cover crop management on nitrate leaching losses and crop growth. *The Journal of Agricultural Science*, *131*(3), 299–308. https://doi.org/10.1017/S0021859698005899

Franzluebbers, A. J., & Stuedemann, J. A. (2007). Crop and cattle responses to tillage systems for integrated crop-livestock production in the Southern Piedmont, USA. *Renewable Agriculture and Food Systems*, *22*(3), 168–180. https://doi.org/10.1017/S1742170507001706

Franzluebbers, A. J., & Stuedemann, J. A. (2008). Soil physical responses to cattle grazing cover crops under conventional and no tillage in the Southern Piedmont USA. *Soil and Tillage Research*, *100*(1–2), 141–153. https://doi.org/10.1016/j.still.2008.05.011

Franzluebbers, A. J., & Stuedemann, J. A. (2015). Does grazing of cover crops impact biologically active soil carbon and nitrogen fractions under inversion or no tillage management? *Journal of Soil and Water Conservation*, *70*(6), 365–373. https://doi.org/10.2489/jswc.70.6.365

Galindo, F. S., Delate, K., Heins, B., Phillips, H., Smith, A., & Pagliari, P. H. (2020). Cropping system and rotational grazing effects on soil fertility and enzymatic activity in an integrated organic crop-livestock system. *Agronomy*, *10*(6), 1–18. https://doi.org/10.3390/agronomy10060803

Ganjegunte, G. K., Vance, G. F., Preston, C. M., Schuman, G. E., Ingram, L. J., Stahl, P. D., & Welker, J. M. (2005). Soil Organic Carbon Composition in a Northern Mixed-Grass Prairie. *Soil Science Society of America Journal*, *69*(6), 1746–1756. https://doi.org/10.2136/sssaj2005.0020

Gezahegn, A., Halim, M., Mohammad Yusoff, M., & W., S. (2019). *Decomposition and Nitrogen mineralization of Individual and Mixed Maize and Soybean Residue*.

Ghimire, B., Ghimire, R., Vanleeuwen, D., & Mesbah, A. (2017). *Cover Crop Residue Amount and Quality Effects on Soil Organic Carbon Mineralization*. 1–14. https://doi.org/10.3390/su9122316

Goering, H. K., & Van Soest, P. J. (1970). *Forage fiber analyses (apparatus, reagents, procedures, and some applications)*. U.S. Agricultural Research Service; [for sale by the Supt. of Docs., U.S. Govt. Print. Off.

Gougoulias, C., Clark, J. M., & Shaw, L. J. (2014). The role of soil microbes in the global carbon cycle: Tracking the below-ground microbial processing of plant-derived carbon for manipulating carbon dynamics in agricultural systems. *Journal of the Science of Food and Agriculture*, *94*(12), 2362–2371. https://doi.org/10.1002/jsfa.6577

Grossman, R. B., & Reinsch, T. G. (2002). 2.1 Bulk Density and Linear Extensibility. In *Methods of Soil Analysis* (pp. 201–228). John Wiley & Sons, Ltd. https://doi.org/10.2136/sssabookser5.4.c9

Guo, M. (2021). Soil Health Assessment and Management: Recent Development in Science and Practices. *Soil Systems*, *5*(4), 61. https://doi.org/10.3390/soilsystems5040061

Halde, C., Hammermeister, A. M., L. Mclean, N., Webb, K. T., & Martin, R. C. (2011). Soil compaction under varying rest periods and levels of mechanical disturbance in a rotational grazing system. *Canadian Journal of Soil Science*, *91*(6), 957–964. https://doi.org/10.4141/cjss2011-026

Hamilton, E. W., & Frank, D. A. (2001). Can Plants Stimulate Soil Microbes and Their Own Nutrient Supply? Evidence from a Grazing Tolerant Grass. *Ecology*, *82*(9), 2397–2402. https://doi.org/10.2307/2679923

Hinsinger, P., Bengough, A. G., Vetterlein, D., & Young, I. M. (2009). Rhizosphere: Biophysics, biogeochemistry and ecological relevance. *Plant and Soil*, *321*(1–2), 117–152. https://doi.org/10.1007/s11104-008-9885-9

Holechek, J. L. (1988). An Approach for Setting the Stocking Rate. *10*. https://repository.arizona.edu/handle/10150/640265

Joshi Gyawali, A., Lester, B. J., & Stewart, R. D. (2019). Talking SMAAC: A New Tool to Measure Soil Respiration and Microbial Activity. *Frontiers in Earth Science*, *7*. https://www.frontiersin.org/article/10.3389/feart.2019.00138

Józefowska, A., Woźnica, K., Sokołowska, J., Sochan, A., Zaleski, T., Ryżak, M., & Bieganowski, A. (2021). Stability of Aggregates Made by Earthworms in Soils with Organic Additives. *Agronomy*, *11*(3), 421. https://doi.org/10.3390/agronomy11030421

Kemper, W. D., & Rosenau, R. C. (1986). Aggregate Stability and Size Distribution. In *Methods of Soil Analysis* (pp. 425–442). John Wiley & Sons, Ltd. https://doi.org/10.2136/sssabookser5.1.2ed.c17

Kim, N., Zabaloy, M. C., Guan, K., & Villamil, M. B. (2020). Do cover crops benefit soil microbiome? A meta-analysis of current research. *Soil Biology and Biochemistry*, *142*, 107701. https://doi.org/10.1016/j.soilbio.2019.107701

Klopfenstein, T., Roth, L., Rivera, S. F., & Lewis, M. (1987). Corn Residues in Beef Production Systems. *Journal of Animal Science*, *65*(4), 1139–1148. https://doi.org/10.2527/jas1987.6541139x

Kong, A. Y. Y., Scow, K. M., Córdova-Kreylos, A. L., Holmes, W. E., & Six, J. (2011). Microbial community composition and carbon cycling within soil microenvironments of conventional, low-input, and organic cropping systems. *Soil Biology & Biochemistry*, *43*(1), 20–30.

Krueger, E. S., Ochsner, T. E., Porter, P. M., & Baker, J. M. (2011). Winter rye cover crop management influences on soil water, soil nitrate, and corn development. *Agronomy Journal*, *103*(2), 316–323. https://doi.org/10.2134/agronj2010.0327

Krupnik, T. J., Timsina, J., Devkota, K. P., Tripathi, B. P., Karki, T. B., Urfels, A., Gaihre, Y. K., Choudhary, D., Beshir, A. R., Pandey, V. P., Brown, B., Gartaula, H., Shahrin, S., & Ghimire, Y. N. (2021). Chapter Four—Agronomic, socio-economic, and environmental challenges and opportunities in Nepal's cereal-based farming systems. In D. L. Sparks (Ed.), *Advances in Agronomy* (Vol. 170, pp. 155–287). Academic Press. https://doi.org/10.1016/bs.agron.2021.06.004

Lemaire, G., Franzluebbers, A., Carvalho, P. C. de F., & Dedieu, B. (2014). Integrated crop–livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. *Agriculture, Ecosystems & Environment*, *190*, 4–8. https://doi.org/10.1016/j.agee.2013.08.009

Lepcha, I., & Naumann, H. D. (2021). Partitioning of Forage Mass and Nutritive Value in Sunn Hemp Leaf and Stem Components. *International Journal of Agronomy*, *2021*, e5547120. https://doi.org/10.1155/2021/5547120

Liebig, M. A., Tanaka, D. L., Kronberg, S. L., Scholljegerdes, E. J., & Karn, J. F. (2012). Integrated crops and livestock in central North Dakota, USA: Agroecosystem management to buffer soil change. *Renewable Agriculture and Food Systems*, *27*(2), 115–124. https://doi.org/10.1017/S1742170511000172

Lindsey, L. (2018). *Double Crop Soybean Considerations | Agronomic Crops Network*. Agronomic Crop Network. https://agcrops.osu.edu/newsletter/corn-newsletter/2018-17/double-crop-soybean-considerations

Lingenfelter, D. (2006). *Cover Crops for Conservation Tillage Systems*. Penn State Extension. https://extension.psu.edu/cover-crops-for-conservation-tillage-systems

Liu, M., Han, G., & Zhang, Q. (2019). Effects of Soil Aggregate Stability on Soil Organic Carbon and Nitrogen under Land Use Change in an Erodible Region in Southwest China. *International Journal of Environmental Research and Public Health*, *16*(20), 3809. https://doi.org/10.3390/ijerph16203809

McNaughton, S. J. (1979). Grazing as an Optimization Process: Grass-Ungulate Relationships in the Serengeti. *The American Naturalist*, *113*(5), 691–703. https://doi.org/10.1086/283426

Morris, J. L., Allen, V. G., Vaughan, D. H., Luna, J. M., & Cochran, M. A. (1998). Establishment of corn in rotation with alfalfa and rye: Influence of grazing, tillage, and herbicides. *Agronomy Journal*, *90*(6), 837–844. https://doi.org/10.2134/agronj1998.00021962009000060020x

Nair, A., & Ngouajio, M. (2012). Soil microbial biomass, functional microbial diversity, and nematode community structure as affected by cover crops and compost in an organic vegetable production system. *Applied Soil Ecology*, *58*(July), 45–55. https://doi.org/10.1016/j.apsoil.2012.03.008

Nimmo, J. R., Schmidt, K. M., Perkins, K. S., & Stock, J. D. (2009). Rapid Measurement of Field-Saturated Hydraulic Conductivity for Areal Characterization. *Vadose Zone Journal*, *8*(1), 142–149. https://doi.org/10.2136/vzj2007.0159

NOAA National Centers for Environmental Information. (n.d.). *Climate Data Online (CDO)—The National Climatic Data Center's (NCDC) Climate Data Online (CDO) provides free access to NCDC's archive of historical weather and climate data in addition to station history information. | National Climatic Data Center (NCDC)*. Retrieved March 14, 2022, from https://www.ncdc.noaa.gov/cdo-web/

Norris, C. E., & Congreves, K. A. (2018). Alternative Management Practices Improve Soil Health Indices in Intensive Vegetable Cropping Systems: A Review. *Frontiers in Environmental Science*, *6*. https://www.frontiersin.org/article/10.3389/fenvs.2018.00050

Nosetto, M. D., Jobbágy, E. G., & Paruelo, J. M. (2006). Carbon sequestration in semi-arid rangelands: Comparison of Pinus ponderosa plantations and grazing exclusion in NW Patagonia. *Journal of Arid Environments*, *67*(1), 142–156. https://doi.org/10.1016/j.jaridenv.2005.12.008

Obour, A. K., Simon, L. M., Holman, J. D., Carr, P. M., Schipanski, M., Fonte, S., Ghimire, R., Nleya, T., & Blanco-Canqui, H. (2021). Cover crops to improve soil health in the North American Great Plains. *Agronomy Journal*, *113*(6), 4590–4604. https://doi.org/10.1002/agj2.20855

Paudel, G., Bhatta, M., Mahato, M., Joshi, D., & Shrestha, J. (2021). *Genotype and nitrogen effects on grain yield and yield-related traits of maize (Zea mays L.) hybrids*. https://doi.org/10.15159/jas.21.37

Peng, X., Heitman, J., Horton, R., & Ren, T. (2017). Determining Near-Surface Soil Heat Flux Density Using the Gradient Method: A Thermal Conductivity Model–Based Approach. *Journal of Hydrometeorology*, *18*(8), 2285–2295. https://doi.org/10.1175/JHM-D-16-0290.1

Perelman, S., León, R., & Bussacca, J. P. (1997). *Floristic changes related to grazing intensity in a Patagonian shrub steppe*. https://doi.org/10.1111/J.1600-0587.1997.TB00385.X

Planisich, A., Utsumi, S. A., Larripa, M., & Galli, J. R. (2021). Grazing of cover crops in integrated crop-livestock systems. *Animal*, *15*(1), 100054. https://doi.org/10.1016/j.animal.2020.100054

Poffenbarger, H. (2010). Ruminant Grazing of Cover Crops: Effects on Soil Properties and Agricultural Production. *Journal of Natural Resources and Life Sciences Education*, *39*(1), 49–39. https://doi.org/10.4195/jnrlse.2010.0003se

Quigley, K. M., & Anderson, T. M. (2014). Leaf silica concentration in Serengeti grasses increases with watering but not clipping: Insights from a common garden study and literature review. *Frontiers in Plant Science*, *5*, 568. https://doi.org/10.3389/fpls.2014.00568

Rod, K. S., Shockley, J., & Knott, C. A. (2021). Seed yield, seed quality, profitability, and risk analysis among double crop soybean maturity groups and seeding rates. *Agronomy Journal*, *113*(2), 1792–1802. https://doi.org/10.1002/agj2.20626

Rushing, J. B., Saha, U. K., Lemus, R., Sonon, L., & Baldwin, B. S. (2016). Analysis of Some Important Forage Quality Attributes of Southeastern Wildrye (<i>Elymus glabriflorus</i>) Using Near-Infrared Reflectance

Spectroscopy. *American Journal of Analytical Chemistry*, *07*(09), 642–662. https://doi.org/10.4236/ajac.2016.79060

Schindelbeck, R. R., Moebius-Clune, D. J., Moebius-Clune, B. N., & Kurtz, K. Z. (2016). *Cornell Soil Health Laboratory Comprehensive Assessment of Soil Health Standard Operating Procedures February 2016*. Https://Soilhealth.Cals.Cornell.Edu/. https://soilhealth.cals.cornell.edu/

Schomberg, H. H., Fisher, D. S., Reeves, D. W., Endale, D. M., Raper, R. L., Jayaratne, K. S. U., Gamble, G. R., & Jenkins, M. B. (2014). Grazing winter rye cover crop in a cotton no-till system: Yield and economics. *Agronomy Journal*, *106*(3), 1041–1050. https://doi.org/10.2134/agronj13.0434

Shah, S., Hookway, S., Pullen, H., Clarke, T., Wilkinson, S., Reeve, V., & Fletcher, J. M. (2017). The role of cover crops in reducing nitrate leaching and increasing soil organic matter. *Aspects of Applied Biology*, *134*(August), 243–251.

Shapiro, B. I., Brorsen, B. W., & Doster, D. H. (1992). Adoption of double-cropping soybeans and wheat. *Southern Journal of Agricultural Economics*, *24*(2), 33–40. https://doi.org/10.1017/s0081305200018355

Sharma, P., Singh, A., Kahlon, C. S., Brar, A. S., Grover, K. K., Dia, M., & Steiner, R. L. (2018). The Role of Cover Crops towards Sustainable Soil Health and Agriculture—A Review Paper. *American Journal of Plant Sciences*, *9*(9), 1935–1951. https://doi.org/10.4236/ajps.2018.99140

Shober, A. L., & Taylor, R. (2014). *Nitrogen Management for Soybeans | Cooperative Extension | University of Delaware*. https://www.udel.edu/academics/colleges/canr/cooperative-extension/fact-sheets/nitrogen-management-soybeans/

Singer, J. W., Nusser, S. M., & Alf, C. J. (2007). Are cover crops being used in the US corn belt? *Journal of Soil and Water Conservation*, *62*(5), 353–358.

Six, J., Elliott, E. T., & Paustian, K. (1999). Aggregate and Soil Organic Matter Dynamics under Conventional and No-Tillage Systems. *Soil Science Society of America Journal*, *63*(5), 1350–1358. https://doi.org/10.2136/sssaj1999.6351350x

Sparrow, A. D., Friedel, M. H., & Tongway, D. (2003). Degradation and recovery processes in arid grazing lands of central Australia Part 3: Implications at landscape scale. *Journal of Arid Environments*, *55*, 349–360. https://doi.org/10.1016/S0140-1963(03)00027-2

Thapa, S., All, J., & Yadav, R. K. P. (2016). Effects of Livestock Grazing in Pastures in the Manaslu Conservation Area, Nepalese Himalaya. *Mountain Research and Development*, *36*(3), 311–319. https://doi.org/10.1659/MRD-JOURNAL-D-13-00066.1

Tigner, R. (2018). *Partial Budgeting: A Tool to Analyze Farm Business Changes | Ag Decision Maker*. https://www.extension.iastate.edu/agdm/wholefarm/html/c1-50.html

Tobin, C., Singh, S., Kumar, S., Wang, T., & Sexton, P. (2020). Demonstrating Short-Term Impacts of Grazing and Cover Crops on Soil Health and Economic Benefits in an Integrated Crop-Livestock System in South Dakota. *Open Journal of Soil Science*, *10*(03), 109. https://doi.org/10.4236/ojss.2020.103006

Tollner, E. W., Calvert, G. V., & Langdale, G. (1990). Animal trampling effects on soil physical properties of two Southeastern U.S. ultisols. *Agriculture, Ecosystems & Environment*, *33*(1), 75–87. https://doi.org/10.1016/0167-8809(90)90145-4

Tracy, B. F., & Zhang, Y. (2008). Soil compaction, corn yield response, and soil nutrient pool dynamics within an integrated crop-livestock system in Illinois. *Crop Science, 48*(3), 1211–1218. https://doi.org/10.2135/cropsci2007.07.0390

USDA's National Agricultural Statistical Service. (2020). *USDA - National Agricultural Statistics Service—Pennsylvania—Annual Statistical Bulletins*. USDA. https://www.nass.usda.gov/Statistics_by_State/Pennsylvania/Publications/Annual_Statistical_Bulletin/index.php

Vera, R. R. (1991). Grazing management: Science into practice : By John Hodgson. Longman Handbooks in Agriculture, 1990. Longman Scientific & Technical, Harlow, Essex, UK. 203 pp. ISBN 0 582 45010 1. Price: [pound sign]11.95 (paperback). *Agricultural Systems*, *37*(2), 219–220.

Warren, S. D., Nevill, M. B., Blackburn, W. H., & Garza, N. E. (1986). Soil Response to Trampling Under Intensive Rotation Grazing. *Soil Science Society of America Journal*, *50*(5), 1336–1341. https://doi.org/10.2136/sssaj1986.03615995005000050050x

Weil, R. R., Islam, K. R., Stine, M. A., Gruver, J. B., & Samson-Liebig, S. E. (2003). Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *American Journal of Alternative Agriculture*, *18*(1), 3–17. https://doi.org/10.1079/AJAA2003003

White, K. E., Brennan, E. B., Cavigelli, M. A., & Smith, R. F. (2020). Winter cover crops increase readily decomposable soil carbon, but compost drives total soil carbon during eight years of intensive, organic vegetable production in California. *PLoS ONE*, *15*(2), e0228677. https://doi.org/10.1371/journal.pone.0228677

White, P. A. (2014). *The Growing Business of Cover Crops*. *August*.

Wilhelm, W. W., Johnson, J. M. F., Karlen, D. L., & Lightle, D. T. (2007). Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply. *Agronomy Journal*, *99*(6), 1665–1667. https://doi.org/10.2134/agronj2007.0150

Wimberly, M. C., Janssen, L. L., Hennessy, D. A., Luri, M., Chowdhury, N. M., & Feng, H. (2017). Cropland expansion and grassland loss in the eastern Dakotas: New insights from a farm-level survey. *Land Use Policy*, *63*, 160–173. https://doi.org/10.1016/j.landusepol.2017.01.026

Wolf, A. M., & Beegle, D. M. (2011). *Recommended Soil Testing Procedures for the Northeastern United States* (3rd ed.). Agricultural Experiment Station, University of Delaware. https://www.udel.edu/academics/colleges/canr/cooperative-extension/fact-sheets/soil-testing-procedures-northeastern-US/

Wright, A. F., & Bailey, J. S. (2001). Organic carbon, total carbon, and total nitrogen determinations in soils of variable calcium carbonate contents using a Leco CN-2000 dry combustion analyzer. *Communications in Soil Science and Plant Analysis*, *32*(19–20), 3243–3258. https://doi.org/10.1081/CSS-120001118

Xia, C., Rahman, M. A. U., Yang, H., Shao, T., Qiu, Q., Su, H., & Cao, B. (2018). Effect of increased dietary crude protein levels on production performance, nitrogen utilisation, blood metabolites and ruminal fermentation of Holstein bulls. *Asian-Australasian Journal of Animal Sciences*, *31*(10), 1643–1653. https://doi.org/10.5713/ajas.18.0125

Yu, C., Miao, R., & Khanna, M. (2021). Maladaptation of U.S. corn and soybeans to a changing climate. *Scientific Reports*, *11*(1), 1–12. https://doi.org/10.1038/s41598-021-91192-5

Zhang, H., & Redfeam, D. (2017, February 1). *Collecting Forage Samples for Analysis—Oklahoma State University*. https://extension.okstate.edu/fact-sheets/collecting-forage-samples-for-analysis.html

Zhu, Y., Merbold, L., Leitner, S., Pelster, D. E., Okoma, S. A., Ngetich, F., Onyango, A. A., Pellikka, P., & Butterbach-Bahl, K. (2020). The effects of climate on decomposition of cattle, sheep and goat manure in Kenyan tropical pastures. *Plant and Soil, 451*(1), 325–343. https://doi.org/10.1007/s11104-020-04528-x

DIVYA PANT | divyapant027@gmail.com| LinkedIn
869 Southgate Dr. 16801, State College, PA(205) 499-2371

ACADEMIC QUALIFICATION

First Generation Graduate Student, The Penn State University, University Park. **GPA: 3.92** Aug 2019-Present.
Major in Agronomy and minor in International Agriculture & development Anticipated graduation date: Fall 2021

B.Sc. in Agriculture, Institute of Agriculture and Animal Science, Lamjung, Nepal. **GPA: 3.9** 2014-2018

SKILLS

Leadership| Public speaking| Research & program design | MS Office & G suite | R studio

PROFESSIONAL EXPERIENCE, RESPONSIBILITIES & ACCOMPLISHMENTS

Graduate Research Assistant, The Pennsylvania State University, University Park Aug 2019-Present

- Assessment of soil physical and biological properties and farm economics in response to management intensive grazing of cover crops planted after corn silage and small grain harvest under no-till system in Pennsylvania.
- Design research and carry data collection, and analysis, develop grant proposal/article/report/journal, and extension of generated findings to support agricultural sustainability.

Founded AgTech startup, "Carbon Compost" and prime investigator of project Sanjeevani Jan 2021- present

- Founded startup Carbon Compost and project Sanjeevani, which is working on developing statistically rigorous tools to form a comprehensive framework to quantifying the GHG emission, CO_2 flux, and sequestration durability along the process of waste recycling through bio digestion, biochar, and vermicomposting.

Joint Secretary and advisory board member, Youth for Agri-Welfare, Lamjung, Nepal Feb 2015- present

- Identify, organize, and coordinate programs/trainings to foster community development, youth mobilization for climate actions, and women empowerment into sustainable agriculture
- Collaborate with Gov, NGO & private funding agencies to organize green climate, leadership/community development program for undergraduates, food security, and conservation agriculture training for farmers.

Extension

- Extensionist at Pasture Walk held in Franklin County, PA to promote Management intensive Grazing of the cover crop among farmers and extensionist of Southeastern Pennsylvania
- Community Level "Integrated Farming and Sustainable Farm Design" project developed for small farm holders, Nepal.

HONORS/ MEMBERSHIP/ SCHOLARSHIP

- Nominated and recognized for outstanding academic achievement and leadership potential at the graduate level by Gamma Sigma Delta honor society for agriculture and agricultural sciences, Penn State University.
- Second runner-up at Ag Springboard student business pitch contest and bagged $2500 as winning prize to carry a pilot project for startup "Carbon Compost".
- Merit scholarship from primary school to bachelor's degree. Outstanding student award at secondary school, Adarsh Vidya Niketan secondary school, Nepal.