CROP PRODUCTION AND SOIL PROPERTIES IMPACTS OF INTEGRATING ANNUAL FORAGES AND LIVESTOCK IN WHEAT-BASED CROPPING SYSTEMS

Z.C. Carson[1], A.K. Obour[1], J.D. Holman[2], and K.L. Roozeboom[3]
[1]Kansas State University, Agricultural Research Center-Hays, Hays, KS; [2]Kansas State University, Southwest Research and Extension Center, Garden City, KS; [3]Kansas State University, Department of Agronomy, Manhattan, KS,
zccarson@ksu.edu (620) 214-3919

ABSTRACT

Integrating annual forages and livestock can increase profitability but potentially negatively impact soil health in dryland cropping systems due to residue removal. The objective of this study was to determine crop yield and soil property impacts of integrating annual forages and livestock in traditional winter wheat (*Triticum aestivum L.*)-grain sorghum (*Sorghum bicolor Moench*)-fallow rotation (W-GS-F). Initiated in 2021 near Hays Kansas, treatments included W-GS-F (control), W-GS-F with GS residues grazed (W-GSG-F), wheat/forage sorghum-forage sorghum-fallow (W/FS-FS-F) with FS grazed (W/FSG-FSG-F), and FS hayed (W/FSH-FSH-F) in a randomized complete block design with four replications. Full-season FS harvested for hay averaged 6,546 lb/ac, while post-wheat FS averaged 2,582 lb/ac. Each harvesting period left ~30 % of biomass remaining as residue. Before grazing, full-season FS produced 6,184 lb/ac with ~50 % of biomass remaining as residue after livestock removal. Post-wheat FS plots were grazed in 3 out of 5-years, and produced 2,632 lb/ac before grazing with ~60 % of biomass remaining as residue post-graze. Wheat and grain sorghum yields did not differ across treatments. Soil cover and properties were sampled prior to wheat planting each sampling year. The W/FSG-FSG-F had the most soil cover and least penetration resistance. No differences in bulk density were observed when averaged across the 0-6 in depth. Despite no differences in bulk soil organic carbon (SOC), dry aggregate associated SOC was greater with W-GSG-F and W/FSG-FSG-F than W-GS-F and W/FSH-FSH-F in nearly all aggregate sizes. Soil nitrogen (N) and phosphorus (P) concentrations were not significantly different among treatments. No differences in mean weight diameter (MWD) of water stable aggregates were observed among treatments. Dry-aggregate MWD was similar for W-GS-F, W-GSG-F, and W/FSG-FSG-F treatments, but was significantly less for W/FSH-FSH-F. Percent wind erodible fraction (WEF) was consistently higher for W/FSH-FSH-F. Cropping system net returns varied by year and were significantly greater for W-GSG-F and W/FSG-FSG-F followed by the W-GS-F and least in the W/FSH-FSH-F due to far greater expenses. Overall, integrating annual forages and livestock improved or maintained soil health compared to the control, and was more profitable than haying forages.

INTRODUCTION

Intensifying dryland cropping systems with annual forages and integrating ruminant livestock have the potential to increase profitability, enhance fallow water use efficiency, and improve soil health by increasing residue cover and reducing wind and water erodibility. Currently, the most common crop rotation in this region is winter wheat (W) *(Triticum aestivum L.)*-summer crop-F. The most common summer crops utilized within that rotation are grain sorghum (GS) *(Sorghum bicolor (L.) Moench)* and corn *(Zea mays L.)* (Schlegel et al., 2002). Typically, after the summer crop is harvested, a 12-14-month fallow period ensues to build soil water content for the next wheat crop. Due to high evaporation in this climate, only 17-30% of precipitation is retained as stored soil moisture during the fallow period (Peterson & Westfall et al., 2004). Even with no-till (NT), less than 40% of precipitation is retained, and soil cover is lost. Intensifying the rotation with annual forages may reduce soil water and have a negative impact on subsequent grain yield, but the forage that is produced for grazing and haying may offset negative impacts to profitability. Adding annual forages in wheat-based systems may even boost profitability (Holman et al., 2018, 2021, 2023a, 2023b; Carr et al., 2020). Concerns also may arise with the potentially negative impacts of haying and grazing on soil organic carbon (SOC) reserves, water stable aggregates, and wind erodible fraction due to removal of crop residue. Grazing is often perceived negatively because it may increase soil compaction as indicated by greater bulk density (BD) and penetration resistance (PR). The objective of this study was to analyze crop yield and soil health impacts of intensifying the traditional NT W-GS-F system with annual forages, as well as integrating livestock to graze forages and crop residues.

Materials and Methods

This study was initiated at the Kansas State University Agricultural Research Center-Hays near Hays, KS with all phases of the experiment in place by 2021. The study design was a randomized complete block with four replications in a W-GS-F rotation system. The study compared the W-GS-F rotation with grazing of the GS stalks and with grazing or haying of annual forage sorghum grown in place of GS. Each crop phase and hayed or grazed treatments were present each year. Plots were 90-ft wide x 127-ft long for the grazed treatments, and 30-ft wide x 127-ft long for the hayed treatments. Each treatment was grown under NT conditions.

Treatments:

1. Year 1: winter wheat; Year 2: grain sorghum; Year 3: fallow: (W-GS-F)
2. Year 1: winter wheat; Year 2: grain sorghum (grazed stalks); Year 3: fallow: (W-GSG-F)
3. Year 1: winter wheat/double-crop forage sorghum (grazed); Year 2: forage sorghum (grazed); Year 3: fallow: (W/FSG-FSG-F)
4. Year 1: winter wheat/double-crop forage sorghum (hayed); Year 2: forage sorghum (hayed); Year 3: fallow: (W/FSH-FSH-F)

Winter wheat was planted the end of September, GS and FS were planted at the beginning of June, and post-wheat FS was planted as soon as wheat was harvested. Winter wheat was harvested mid-late June, and GS was harvested mid-October. All grain crops were harvested using a Massey Fergusson 8XP plot combine with a 5-ft header. Grain yields were determined by a single 5-ft x 127-ft pass with the combine. Hayed FS was harvested at the end of August, at a 6-in cutting height. Forage sorghum yields were determined by a single harvest of a 3-ft x 127-ft pass with a Carter forage harvester at heading. Grazing of GS stocks occurred post GS harvest and at heading in FS. To determine FS amount before grazing and haying, a 2-ft x 3-ft quadrant was used to sample two different locations within the plot. After grazing, the sampling was repeated to determine amount of residue remaining.

In August 2023-2025 after the full rotation cycle, soil samples were taken from each plot pre-wheat planting. The soil properties examined were residue cover (RC), wet and dry aggregate stability, BD, PR, SOC, N and P. Residue cover was quantified using the line transect method at two random locations within a plot. Two intact soil samples were collected per plot for aggregate stability and BD, while ten samples per plot were collected for all other soil property analyses. Wet aggregate stability mean weight diameter (MWD) was conducted by the wet sieving method using intact soil samples collected at the 0-2-in depth (Nimmo and Perkins, 2002). Dry aggregate stability was determined using a set of rotary sieves and wind erodible fraction was estimated as proportion of aggregates <0.84 at the 0-2-in depth (Chepil, 1962). Wet and dry aggregates were then analyzed for SOC for the >2mm, 2-0.25mm, and <0.25mm size distributions using the dry combustion method (Helmke et al., 2013). The same method was repeated for bulk SOC at 0-2-in and 2-6-in depths. The POM in samples was determined using the procedure outlined by Cambardella and Elliot (1992) at 0-2-in and 2-6-in depths. Bulk density was determined by the core method with samples taken from 0-2-in and 2-6-in depths (Grossman and Reinsch, 2002). Penetration resistance was determined using an Eijkelkamp Hand Penetrometer (Eijkelkamp Soil & Water, Morrisville, NC). A partial budget approach was used to estimate cropping systems net returns. Net returns were calculated using revenue accrued from each rotation system minus associated production costs after each treatment completed a full cycle. Statistical analyses were completed in the SAS version 9.4 (SAS Institute, 2012, Cary, NC) using PROC GLIMMIX with year and treatment considered fixed and replication considered random. Treatment differences were considered significant at $P \leq 0.1$.

RESULTS AND DISCUSSION

Crop Yields

Available forage mass varied yearly regardless of planting time. Full-season FS production was highest in 2025 (7,421 lb/ac) and lowest in 2022 (5,114 lb/ac). Post-wheat FS produced a maximum of 4,520 lb/ac in 2024, and a minimum of 741 lb/ac in 2022 due to limited soil moisture. Forage mass remaining as residue was significantly impacted by harvest type in both full-season and post-wheat FS production. Overall, grazing full-season FS left approximately 3,091 lb/ac of biomass on the soil surface, which represented 50% of the total above ground biomass. Haying of full-season FS left 1,963 lb/ac as residue, about 30% of total forage mass produced.

Post-wheat forage mass remaining was analyzed in 2021, 2024, and 2025. Treatments were not grazed or hayed in 2022 and 2023 because of limited production. Similar to the full-season forage mass, the grazed treatment had significantly more residue remaining on the soil surface (1516 lb/ac) than the hayed treatment (982 lb/ac).

Winter wheat yields were analyzed in 2023-2025, after each treatment completed a full cycle. Yields were low due to below average precipitation in every year but 2025, with an average of 23 bu/ac and no significant differences in yields across treatments. Grain sorghum yields were recorded in 2024 and 2025 after treatments had completed a full cycle. Again, there was no significant yield difference between the grain sorghum treatments (W-GS-F and W-GSG-F), with an average grain yield of 67 bu/ac, limited by precipitation.

Residue Cover

In August 2023, W/FSG-FSG-F had the greatest RC (78%) (Fig. 1). The next highest treatments were W-GS-F (61%) and W/FSH-FSH-F (56%). With W-GSG-F (41%) leaving the least soil cover. However, RC was not significantly different among treatments in 2024, but W/FSG-FSG-F trended higher while W/FSH-FSH-F ranked last. In 2025, residue cover in W/FSG-FSG-F (85%), W-GSG-F (78%), W-GS-F (76%) were not significantly different from one another, but had significantly more RC than the W/FSH-FSH-F (59%) treatment.

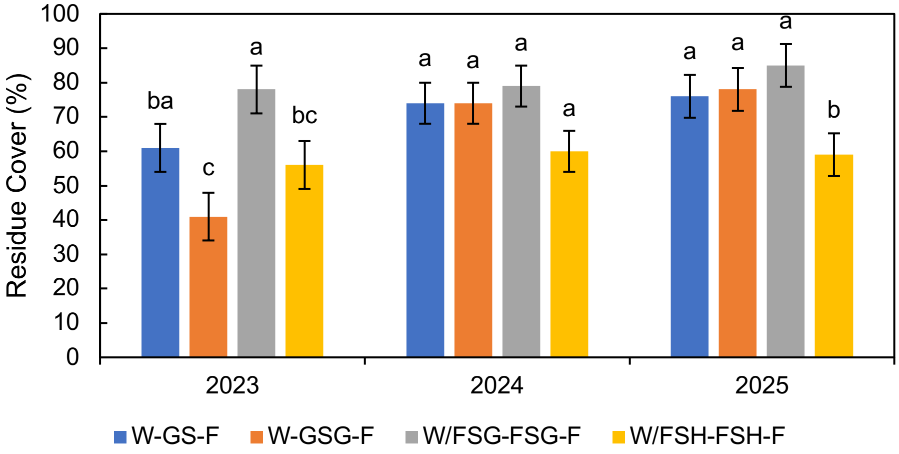

Figure 1. Intensification of W-GS-F with grazing, haying, and forage sorghum effects on residue cover. Means with the same letter within a year are not significantly different *(P≤0.1).*

Soil Organic Carbon and Aggregate Associated Carbon

Despite the differences in RC, bulk SOC was not significantly different among treatments in 2023 and 2024. In 2025, though minimal, W-GSG-F (1.02%) had significantly less bulk SOC than W-GS-F (1.12%), W/FSH-FSH-F (1.09%), and W/FSG-FSG-F (1.08%) treatments. Water stable aggregate-associated carbon at the 0-2-in depth showed no significant differences among treatments. However, treatments differed significantly in dry aggregate-associated carbon in nearly all three size classes. Grazed treatments (W-GSG-F and W/FSG-FSG) ranked first or second in SOC in all aggregate size classes compared to W-GS-F and W/FSH-FSH-F (Fig. 2).

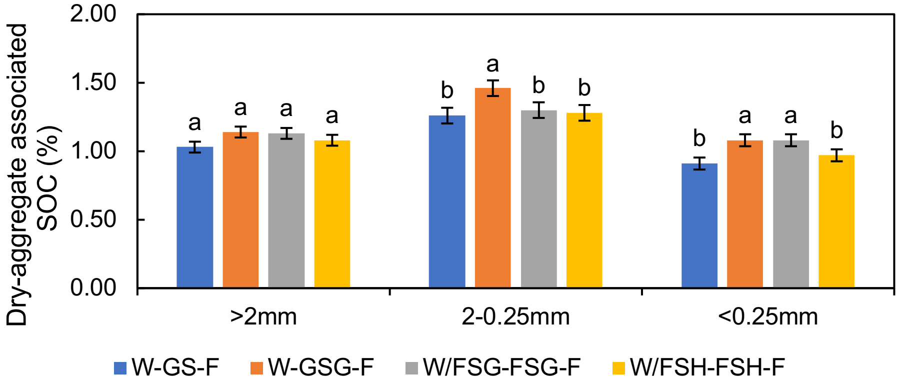

Figure 2. Intensification of W-GS-F with grazing, haying, and forage sorghum effects on dry-aggregate associated SOC. Means with the same letter within a size class are not significantly different *(P≤0.1).*

Nitrogen and Phosphorus

When averaged across the 0-6-in depth, no treatment differences were observed for soil N and P concentrations.

Aggregate Analysis

Wet aggregate MWD did not differ among treatments at the 0-2-in depth. Treatments W-GS-F (6.04 mm), W/FSG-FSG-F (5.62 mm), and W-GSG-F (5.59 mm) had similar dry-aggregate MWD, but W/FSH-FSH-F (4.99 mm) had significantly smaller dry-aggregate MWD compared to other treatments due to minimal soil RC. Therefore, W/FSH-FSH-F consistently exhibited greater percent wind erodible fraction (WEF) in all sampling years (Fig. 3).

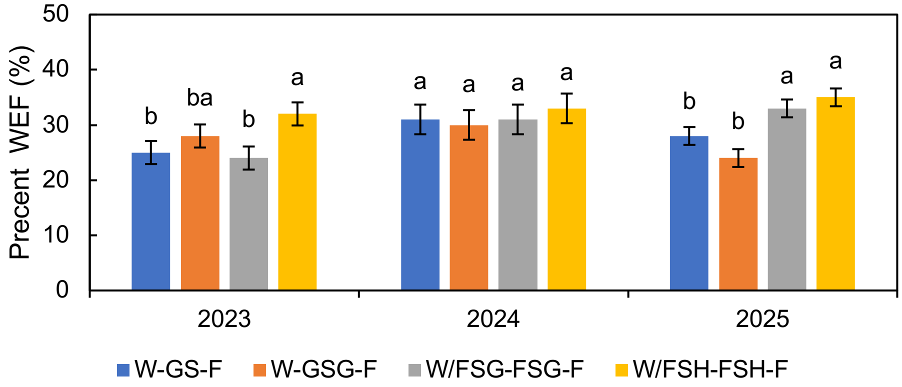

Figure 3. Intensification of W-GS-F with grazing, haying, and forage sorghum effects on dry-aggregate associated SOC. Means with the same letter within a year are not significantly different *(P≤0.1).*

Measures of Soil Compaction

Bulk density did not differ among treatments averaged across the 0-6-in depth. However, averaged across years, PR was significantly higher in the less-intensive cropping systems W-GS-F (0.73 MPa) and W-GSG-F (0.73 Mpa), than W/FSG-FSG-F (0.63 MPa) and W/FSH-FSH-F (0.64 MPa).

System Net Returns

Averaged across 2024 and 2025, the net returns of grazed treatments (W-GSG-F and W/FSG-FSG-F) were greater than W-GS-F and W/FSH-FSH-F (Tab. 1). This is primarily due to high costs associated with baling, and low costs associated with forage for grazing.

Table 1. 2024 and 2025 average effect of rotation Intensification and haying and grazing on production net returns.

Management	Unit	W-GS-F	W-GSG-F	W/FSG-FSG-F	W/FSH-FSH-F
Total Revenue	$/ac	484.37	598.74	503.61	569.93
Total Cost	$/ac	389.88	391.30	356.63	509.31
Net Return	**$/ac**	**94.49cb**	**207.44a**	**146.98b**	**60.62c**

Net Return means with the same letter are not significantly different *(P≤0.1)*

Conclusion

Intensification of W-GS-F with annual forages and grazing increased RC, and dry-aggregate SOC. Haying of annual forages diminished RC and dry-aggregate MWD, increasing percent WEF. Intensification with annual forages decreased PR, and had no significant effect on BD. Intensification and harvest type had no effect on bulk SOC, wet-aggregate SOC, N and P, and wet-aggregate MWD when compared to W-GS-F and W-GSG-F. The W-GSG-F treatment had the highest net returns, followed by W/FSG-FSG-F, then W-GS-F and W/FSH-FSH-F. Overall, grazing had positive or neutral impacts on soil health, while providing greater net returns.

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