Crop Production and Soil Properties Impacts of Integrating Annual Forages and Ruminant Livestock into Wheat-Based Cropping Systems

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Summary

Integrating annual forages and ruminant livestock to intensify dryland cropping systems can increase profitability, increase water use efficiency, and improve soil health. The objective of this study was to determine the crop yield and soil property impacts of intensifying traditional no-till winter wheat (*Triticum aestivum* L.)-grain sorghum (*Sorghum bicolor* Moench)-fallow (WW-GS-F) with annual forages as well as integrating livestock to graze forages and crop residues. This study was initiated in 2021 at the Kansas State University Agricultural Research Center-Hays in Hays, KS. Treatments were WW-GS-F (control), WW-GS-F with grain sorghum residues grazed, winter wheat/forage sorghum-forage sorghum-fallow (WW/FS-FS-F) with forage sorghum grazed, and WW/FS-FS-F with forage sorghum hayed. The treatments were replicated four times with all phases of the rotation present each year. Grain yields were determined in 2023 and 2024, while forage yields were determined every year with sampling to characterize soil properties in the fall of 2023 and 2024. Results showed that full-season forage sorghum harvested for hay produced 5255 lb/a on average, while post-wheat forage sorghum harvested for hay produced 2042 lb/a. Before grazing, full-season forage sorghum produced 8617 lb/a with about 51% of biomass remaining as residue after livestock were removed. On average, post-wheat forage sorghum produced 3399 lb/a before grazing. Because of smaller yields, post-wheat forage sorghum plots were grazed in only 2 years when 46% of biomass remained as residue on the plots after livestock were removed. In 2023 and 2024, WW yields averaged 16 bu/a due to dry weather, with no difference among treatments. Averaged across 2023 and 2024, the WW/FS-FS-F (grazed) treatment had greater crop residue cover (78%) at winter wheat planting than all other treatments (63%). No differences in bulk density in the 0- to 2-inch and 2- to 6-inch soil depths were observed across treatments. While penetration resistance did not show any differences in the top 0- to 2-inch depth, there was a significant decrease in penetration resistance in the 2- to 6-inch depth with WW/FS-FS-F treatments. Despite no differences in bulk soil organic carbon (SOC) in the 0- to 2-inch and 2- to 6-inch soil depths, dry and wet aggregate associated SOC was significantly greater with WW-GS-F (grazed) and WW/FS-FS-F (grazed) treatments than WW-GS-F and WW/FS-FS-F (hayed). No differences in mean weight diameter (MWD) of water stable aggregates or the wind-erodible fraction were observed across treatments. These preliminary results suggest that intensifying the WW-GS-F rotation

with annual forages and integrating livestock increased available forage, soil residue cover, and aggregate associated organic carbon with no effect on winter wheat yields.

Introduction

Intensifying dryland cropping systems with annual forages and integrating ruminant livestock can 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 (WW)-summer crop-F. The most common 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- to 14-month fallow period is used to build soil water content for the next WW crop. Due to high evaporation in this climate, only 17% to 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 half of the 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., 2023). Concerns also may arise with the negative impacts that haying and grazing could potentially have on soil organic carbon (SOC) reserves, water-stable aggregates, and wind-erodible fraction due to grazing or haying the crop residue. Grazing is often seen negatively as it may increase soil compaction as indicated by greater bulk density (BD) and penetration resistance (PR). The objective of this study was to determine crop yield and soil health impacts of intensifying a traditional NT WW-GS-F system with annual forages, and integrating ruminant livestock to graze forages and crop residues.

Procedures

This study was initiated at the Kansas State University Agricultural Research Center-Hays in 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 WW-GS-F rotation system. The study compared a WW-GS-F rotation with grazing of the GS stalks and with grazing or haying of annual forages grown in place of GS. Each crop phase and the hayed or grazed treatments were present each year. The plots were 60-ft wide by 127-ft long for the grazed treatments, and 30-ft wide by 127-ft long for the hayed treatments. Each treatment was grown under NT conditions.

Treatments:

Year 1: winter wheat; Year 2: grain sorghum; Year 3: fallow: (WW-GS-F)

Year 1: winter wheat; Year 2: grain sorghum (grazed stalks);
Year 3: fallow: (WW-GSG-F)

Year 1: winter wheat/double-crop forage sorghum (grazed);
Year 2: forage sorghum (grazed); Year 3: fallow: (WW/FSG-FSG-F)

Year 1: winter wheat/double-crop forage sorghum (hayed);
Year 2: forage sorghum (hayed); Year 3: fallow: (WW/FSH-FSH-F)

Winter wheat was planted at the end of September, GS and FS were planted at the beginning of June, and post-wheat FS was planted as soon as WW was harvested. Winter wheat was harvested in mid-late June, and GS was harvested in mid-October. All grain crops were harvested using a Massey Fergusson 8XP plot combine with a 5-ft wide header attached. Grain yields were determined by a single 5-ft by 127-ft pass with the combine. Hayed FS was harvested at the end of August. Forage sorghum yields were determined by a single harvest of a 3-ft by 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 the FS amount before grazing, a 2-ft by 3-ft quadrant was used to sample two different locations within the plot. After grazing, the methods were repeated to determine the amount of residue remaining.

In August 2023 and 2024, soil samples were collected and residue cover (RC) was measured from each plot pre-wheat planting. The soil properties examined were RC, wet and dry aggregate stability, BD, PR, SOC, and particulate organic matter (POM). Residue cover was analyzed using the line transect method. Two samples were collected per plot for aggregate stability and BD, while 10 soil samples per plot were collected for all other soil property analyses. Wet aggregate stability (MWD) was conducted by the wet sieving method using intact soil samples collected at the 0- to 2-inch depth (Nimmo and Perkins, 2002). Dry aggregate stability was determined using a set of rotary sieves, and the wind erodible fraction was estimated as the proportion of aggregates <0.84 mm at the 0- to 2-inch depth (Chepil, 1962). Wet and dry aggregates were then analyzed for SOC for the >2 mm, 2- to 0.25 mm, and <0.25 mm size distributions using the dry combustion method (Helmke et al., 2013). Particulate organic matter was determined using the procedure outlined by Cambardella and Elliot (1992) at the 0- to 2-inch and 2- to 6-inch depths. Bulk density was determined by the core method with samples taken from 0- to 2-inch and 2- to 6-inch depths (Grossman and Reinsch, 2002). Penetration resistance was determined using an Eijkelkamp Hand Penetrometer (Eijkelkamp Soil & Water, Morrisville, NC). Statistical analyses were completed in SAS version 9.4 (SAS Institute, 2012, Cary, NC) using PROC GLIMMIX with year and treatment considered as fixed and replication considered random. Treatment differences were considered significant at $P < 0.05$.

Results and Discussion

Crop yields

Average hayed full season FS removed 5255 lb/a, while post-wheat hayed FS removed 2042 lb/a (6 inches of stalk remaining after haying). The maximum hayed full season FS removed was in 2021 (8812 lb/a), while the maximum post-wheat hayed FS removed was in 2024 (3703 lb/a) for hayed treatments. Full season grazed FS produced 8617 lb/a on average before grazing and left approximately 51% of the forage as residue. Post-wheat FS was grazed for only two years during the study due to extreme droughts in 2022 and 2023. The maximum post-wheat FS was produced in 2021 (5348 lb/a), and approximately 82% of the total biomass was left after grazing due to trampling.

Due to a severe hail event in 2021 and an extreme drought in 2022, the only WW yields recorded were in 2023 and 2024. Yields were low due to dry weather, with an average of 16 bu/a and no significant differences in yields across treatments (data not shown).

Grain sorghum yield has only been recorded in 2024 after treatments had completed a full phase (3 years). There was no significant yield difference between the grain sorghum treatments (W-GS-F and W-GSG-F), with an average grain yield of 51 bu/a (data not shown).

Residue cover and soil properties

Averaged across years, the WW/FSG-FSG-F had the greatest residue cover (78%) (Figure 1). The next highest treatment was WW-GS-F (68%), with WW/FSH-FSH-F and WW-GSG-F having the least cover (58%).

Despite the differences in residue cover, bulk SOC was not significantly different among treatments. However, treatments differed significantly in dry and wet aggregate-associated carbon in all three aggregate size classes (>2 mm, 2-0.25 mm, and >0.25 mm) (Figure 2). Grazed treatments (WW-GSG-F and WW/FSG-FSG) ranked first or second in SOC in nearly all aggregate size classes compared to WW-GS-F and WW/FSH-FSH-F. Meaning although we have not seen a difference in bulk SOC, we are seeing an accumulation and stabilization of carbon within the individual aggregates, which can increase long-term carbon sequestration. However, POM measured in 2023 and 2024 did not differ among treatments at the 0- to 2-inch or 2- to 6-inch depths. Similarly, average wet aggregate stability and dry aggregate stability (MWD) and wind erodible fraction were not different across treatments at the 0- to 2-inch depth. Soil compaction indicator, BD, measured in 2023 and 2024 at 0- to 2-inch and 2- to 6-inch depths was not different across treatments. While penetration resistance was not different in the 0- to 2-inch depth, it was significantly different in the 2-to 6-inch depth, with the more intensive cropping rotations (WW/FSG-FSG-F and WW/FSH-FSH-F) having a lower penetration resistance (Table 1).

Conclusion

Intensifying the WW-GS-F rotation with annual forages and integrating ruminant livestock significantly increased aggregate associated organic carbon and residue cover, while the intensification decreased PR in the 2- to 6-inch depth. The addition of annual forages and livestock had no effect on MWD, WEF, BD, bulk SOC, WW, and GS yields. These results occurred while making an additional forage available for haying and grazing, potentially increasing profits.

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Table 1. Treatment effects on average soil organic carbon (SOC), particulate organic matter (POM), soil bulk density (BD), penetration resistance (PR), mean weight diameter (MWD) of water stable aggregates, and wind-erodible fraction (WEF) in 2023 and 2024 near Hays, KS

Depth	Treatment	SOC	POM	PR	BD	MWD	WEF
		%	%	MPa	g/cm^{-3}	mm	%
0-2 in	W-GS-F	1.27†	0.58	0.55	1.23	1.0	28
	W-GSG-F	1.31	0.53	0.49	1.22	1.0	29
	W/FSG-FSG-F	1.34	0.59	0.46	1.23	1.1	27
	W/FSH-FSH-F	1.27	0.54	0.56	1.15	1.1	32
2-6 in	W-GS-F	1.09	0.16	0.90a	1.41	---	---
	W-GSG-F	1.16	0.17	0.91a	1.45	---	---
	W/FSG-FSG-F	1.14	0.17	0.75b	1.45	---	---
	W/FSH-FSH-F	1.14	0.18	0.84ba	1.46	---	---

†Means with the same letter are not significantly different across treatments ($\alpha \le 0.05$).

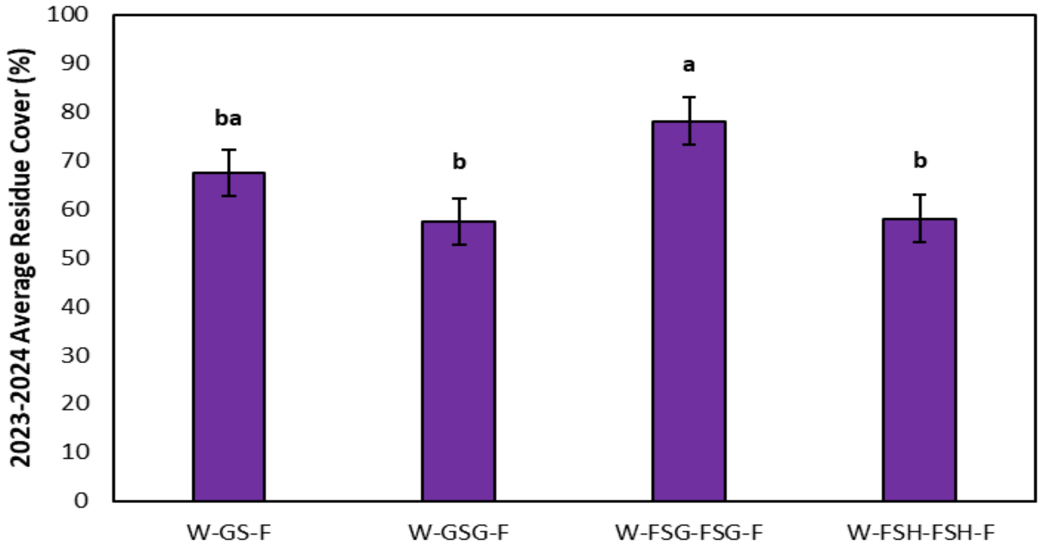

Figure 1. 2023-2024 average effects of intensification of WW-GS-F with grazing and forage sorghum on residue cover. Means with the same letter are not significantly different (P < 0.05).

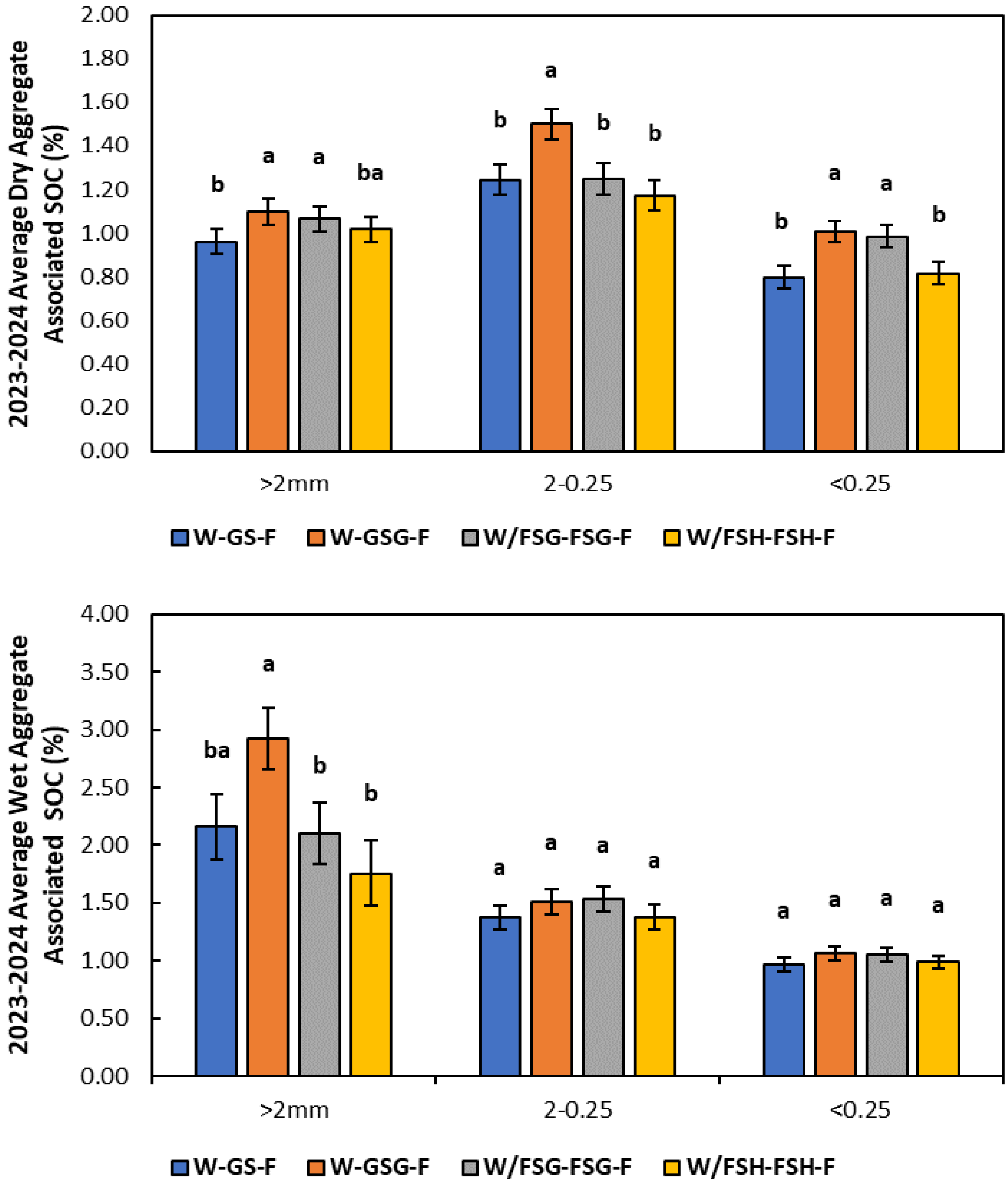

Figure 2. 2023-2024 average effects of intensification of WW-GS-F with grazing and forage sorghum on dry and wet aggregate-associated soil organic carbon (SOC). Means with the same letter are not significantly different ($P < 0.05$).