

# POST-WHEAT SUMMER COVER CROP EFFECTS CROP YIELDS, NET RETURNS, AND SOIL PROPERTIES IN A NO-TILL DRYLAND CROPPING SYSTEM

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## ABSTRACT

Warm-season cover crops (CCs) planted immediately after wheat harvest in the semi-arid central Great Plains (CGP) could intensify cropping systems, increase forage availability, and enhance soil health in no-till (NT) dryland cropping systems. However, the costs of their establishment and potential reductions in subsequent grain yields due to reduced plant-available water present significant barriers to their adoption. This study was conducted from 2016 to 2023 near Brownell, KS, to determine post-wheat CC effects on available forage, grain sorghum yields, net returns, as well as soil properties. The CCs were grown post-wheat in an NT winter wheat (*Triticum aestivum* L.)-grain sorghum-fallow cropping system and either hayed, grazed, or left standing in a split-plot randomized complete block with four replications. Across years, post-wheat CCs produced about 2850 lb ac<sup>-1</sup> available forage, though production was highly variable. Grazing retained about 60% of the available forage as surface residue, while haying retained only about 20%. Grain sorghum yields were reduced 14% on average following CCs compared to fallow. However, average net returns with grazed or hayed CCs were similar to fallow and greater than standing CCs. Most soil properties were unaffected by fallow management, but grazed CCs increased soil organic carbon stocks compared to fallow. Mean weight diameter of water stable aggregates with grazed CCs was similar to fallow and greater than hayed CCs. These results suggest that post-wheat CCs for grazing and haying can intensify cropping systems and increase forage availability while maintaining profitability in the semi-arid CGP.

## INTRODUCTION

Incorporating CCs to replace portions of the fallow periods in dryland cropping systems of the semi-arid CGP could regenerate soils, suppress weeds, and increase precipitation use efficiency (Obour et al., 2021). Warm-season CCs could be planted immediately after wheat harvest and terminated by killing-frost in October (Holman et al., 2023). However, little has been reported about post-wheat CCs in the semi-arid CGP. The costs of their establishment and potential reductions in subsequent grain yields due to reduced plant-available water at planting are significant barriers to their adoption (Obour et al., 2021). Despite this, dual-purpose CCs used for forage may have greater potential to balance profitability and soil health goals in such water-limited environments.

In semi-arid western Kansas, Holman et al. (2023) showed that post-wheat forage sorghum produced about 3500 kg ha<sup>-1</sup> aboveground biomass on average but reduced subsequent grain sorghum yields by 35% compared to fallow. Nevertheless, net returns were similar between these two rotations (Holman et al., 2023). However, how soil health is affected by management strategies like grazing or haying dual-purpose CCs in NT dryland cropping systems of the semi-arid CGP is not yet fully

understood (Simon et al., 2021; 2022). Past research suggested that dual-purpose CCs grown in place of fallow ahead of wheat had similar effects on soil properties as unharvested CCs (Simon et al., 2021). The objectives of this current research were to determine the impact of post-wheat CCs on available forage, grain sorghum yields, net returns, as well as soil chemical and physical properties.

## MATERIALS AND METHODS

This study was conducted from 2016 to 2023 at the KSU HB Ranch near Brownell, KS (22 in average annual precipitation), to investigate best management strategies for CCs to replace fallow in the NT wheat-sorghum-fallow (WSF) cropping system. The study design was a split-plot randomized complete block with four replications. Crop phase was the main plot, and split-plots compared CCs grown post-wheat, managed as standing cover, hayed, or grazed, with chemically controlled NT fallow, for a total of four treatments. Split-plots were 9.1 m wide and 30.5 m long.

Immediately after wheat harvest, a CC mixture of forage sorghum, pearl millet (*Cenchrus americanus* (L.) Morrone), cowpea (*Vigna unguiculata* (L.) Walp.), and sunn hemp (*Crotalaria juncea* L.) was planted at a seeding rate of 7, 2.5, 20, and 5 lb ac<sup>-1</sup>, respectively, using an NT drill. Grazing generally coincided with grass species heading stage and was facilitated using yearling heifers at densities from 782 to 1,565 lb liveweight ac<sup>-1</sup> for 4–7 d in fenced paddocks across the four replications of this study. Each year before grazing was initiated, CC biomass was determined by hand-clipping two areas of 5.4 ft<sup>2</sup> per plot. Samples were dried at approximately 122°F for a minimum of 48 h in a forced-air oven and weighed to determine dry matter. After grazing, each plot was resampled as previously described. Within one week following the last day of grazing, hayed CCs were harvested at a 6-in cutting height using a Carter small plot forage harvester from a strip of 3 ft by 100 ft in the middle of each plot. Whole plot fresh weights were recorded, subsamples collected and weighed, and then oven-dried to determine CC hay yield. The remaining plot area in the hayed plots was harvested after a sample strip was cut. Warm-season CCs were terminated by killing frost, generally near the third week of October.

Each year, winter wheat was planted in the 1st week of October using an NT drill and harvested in early July using a Massey Ferguson 8XP small plot combine harvester. Grain sorghum was planted in the 1st week of June using the same NT drill as used for wheat. Grain sorghum was harvested from mid-October to the 1st week of November using the same small-plot combine harvester as used for wheat. Net returns were calculated for the fallow/CC and subsequent grain sorghum phases of the WSF cropping system as total fallow/CC and grain sorghum revenue minus total fallow/CC and grain sorghum costs for each treatment and year. Estimates of current field operations and input costs used 5-year average custom rate values published by the Kansas State University Land Use Survey Program and the Kansas Department of Agriculture. Five-year average grain sorghum and CC hay prices were taken from the USDA Economic Research Services market reports (USDA ERS, 2021). Cover crop grazing lease rates were estimated using carrying capacity and a grazing lease price based on values published by Iowa State University Ag Decision Maker (Hofstrand & Edwards, 2015). Total variable costs were calculated as the sum of expenses for

fertilizer products and application, herbicide products and application, seed, planting, grain harvesting, and forage swathing and baling.

Soil samples were measured in the field from all plots in summer 2021. Two intact soil cores were randomly taken from the 0-2 and 2-6 in depths. Samples were dried separately at 221°F for 48 hr, and bulk density (BD) was determined as the mass of oven-dry soil divided by the core volume. Additionally, 10 soil cores were randomly collected within each plot, divided into the 0-2 and 2-6 in depths, air-dried, crushed, and sieved to pass through a 2 mm stainless steel screen. A portion of the 2 mm sieved samples was ground with a mortar and pestle to pass through a 0.25 mm sieve, and SOC concentration was determined by dry combustion after pretreating samples with 10% (v/v) HCl to remove carbonates. Carbon mass was calculated by multiplying SOC concentrations by soil BD and the thickness of the soil layer. Soil nitrate-nitrogen (NO<sub>3</sub>-N) concentrations in samples were determined colorimetrically after extraction with 2 M KCl. Available phosphorus (P) was determined by the Mehlich-3 extraction method. Lastly, 5 intact soil samples were carefully collected from the 0-2 and 2-6 soil depths with a flat shovel for the determination of the mean weight diameter (MWD) of water-stable aggregates by the wet-sieving method and the wind-erodible fraction (WEF) (<0.84 mm) by the dry-sieving method.

Analyses of CC biomass accumulation, grain sorghum yields, net returns, and soil properties were conducted using the PROC GLIMMIX procedure in SAS ver. 9.4 (SAS Institute, 2012). For CC biomass, grain yield, and net returns, treatment and year were modeled as fixed effects, with replication treated as random. For BD, SOC, NO<sub>3</sub>-N, P, MWD, and WEF, treatment and soil depth were modeled as fixed effects, with replication treated as random. Treatment effects were considered significant at ( $\alpha = 0.05$ ).

## RESULTS AND DISCUSSION

Despite substantial research attention to replacing fallow before wheat, little information is available on fallow replacement after wheat harvest. Cover crops after wheat could intensify cropping systems and increase forage availability during a time of year when traditional forage resources are limited in the semi-arid CGP (Holman et al., 2023). Post-wheat CCs produced about 2850 lb ac<sup>-1</sup> total biomass on average (Fig. 1). Cover crop biomass accumulation was variable over the study period, with the most significant biomass production in 2016 and 2018 and relatively less in 2019 and 2020. Cover crops failed to establish in 2017 and 2021, and because of limited biomass production in 2019, CCs were not grazed or hayed. On average, aboveground biomass remaining post-grazing was 64% of pre-grazing biomass, which was consistent across years (Fig. 1). However, haying removed 80% of the pre-grazing CC biomass, which was representative of the total biomass present and available for forage. This indicates that haying likely retained only 20% of the aboveground CC biomass as residue. Planting warm-season CCs immediately after wheat harvest to take advantage of soil PAW near the soil surface will improve CC germination and emergence. When planting is delayed, the soil surface may dry, creating a poor environment for crop establishment without timely rainfall, which is unreliable in the semi-arid CGP.

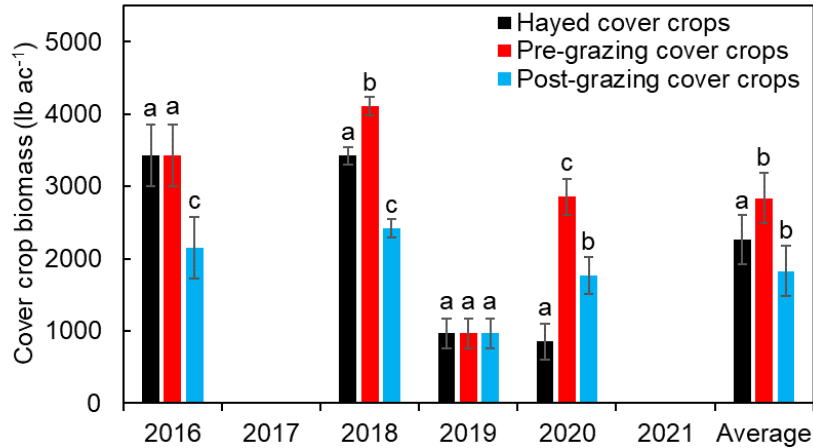


Figure 1. Cover crop biomass from 2016 to 2021 near Brownell, KS. Exceptional drought conditions in 2017 and 2021 resulted in crop failures. Means followed by the same lower-case letter are not significantly different ( $\alpha = 0.05$ ) among cover crop management treatments and bars indicate one standard error of the mean.

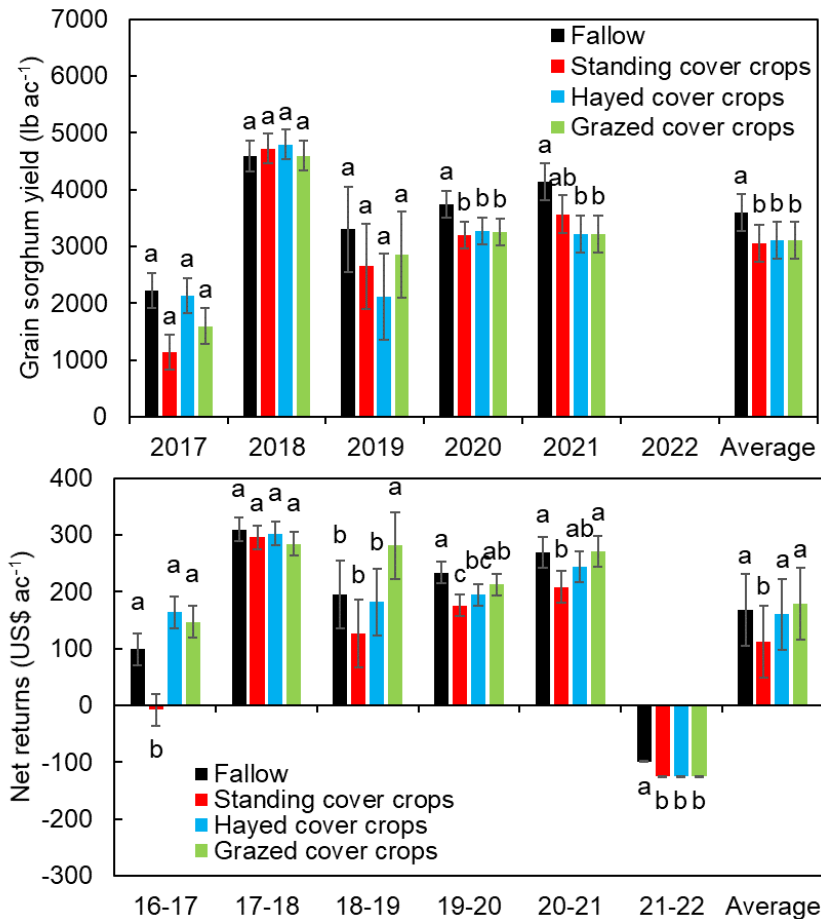


Figure 2. Post-wheat cover crop management effects on subsequent grain sorghum yields and net returns from 2017 to 2022 near Brownell, KS. Exceptional drought conditions in 2022 resulted in crop failures. Means followed by the same lower-case letter are not significantly different ( $\alpha = 0.05$ ) among cover crop management treatments and bars indicate one standard error of the mean.

In semi-arid environments like the CGP, growing-season precipitation alone is not sufficient for stable grain production and is supplemented by PAW stored in soil during fallow periods (Obour et al., 2021). Cover crops reduced subsequent grain sorghum yields by about 14% compared to fallow on average (Fig. 2a). However, fallow management effects varied across years. Grain sorghum yields were unaffected by fallow management in 2017 and 2018. However, CCs reduced grain sorghum yields by 23% and 13% compared to fallow in 2019 and 2020, respectively (Fig. 2a). Interestingly, in 2021, grain sorghum yields were 22% less following hayed or grazed CCs compared to fallow, but standing CCs were not significantly different from fallow. Exceptional drought conditions resulted in a failed grain sorghum crop in 2022. Average net returns with grazed and hayed CCs were similar to fallow and greater than standing CCs (Fig. 2b). Returns with grazed CCs and hayed CCs were similar to fallow in most years except 2018-2019, when grazed CCs netted more than fallow, and 2021-2022, when fallow netted more than grazed or hayed CCs. Fallow had greater net returns than standing CCs in most years except 2017-2018 (Fig. 2b). A significant cost associated with CCs is the seed for planting, and the CC mixture used in the present study was a four-species diverse mixture. Others reported increased expense with broadleaf CC seed but limited biomass production (Holman, 2022). Simple grass-dominated CCs may increase net returns by reducing seed costs and increasing biomass production.

Table 3. Post-wheat cover crop management effects on bulk density (BD), soil organic carbon (SOC), nitrate-N (NO<sub>3</sub>-N), phosphorus (P), mean weight diameter (MWD) of water stable aggregates, and wind-erodible fraction (WEF) in the 0-2 and 2-6 in soil depths in summer 2021 near Brownell, KS.

Management	BD	SOC	NO <sub>3</sub> -N	P	MWD	WEF
	g cm <sup>-3</sup>	ton ac <sup>-1</sup>	ppm	ppm	mm	%
0-2 in						
Fallow	1.17a <sup>†</sup>	3.51bc	21.65a	17.76a	0.84a	34.0a
Standing cover crops	1.14a	3.41c	21.66a	15.31a	0.65ab	31.8a
Hayed cover crops	1.21a	3.75ab	21.18a	17.74a	0.59b	35.9a
Grazed cover crops	1.22a	3.89a	23.29a	19.55a	0.84a	34.3a
2-6 in						
Fallow	1.43a	7.09b	6.44a	11.45a	0.59a	16.8a
Standing cover crops	1.40a	6.87b	6.04a	9.32a	0.69a	19.7a
Hayed cover crops	1.39a	6.87b	5.55a	10.65a	0.66a	16.3a
Grazed cover crops	1.43a	7.63a	7.23a	19.51a	0.88a	15.1a

<sup>†</sup>Means followed by the same lower-case letter within the same column are not significantly different ( $\alpha = 0.05$ ) among treatments.

Despite the economic benefits of grazing or haying CCs, concerns remain that removing CC biomass through grazing or haying could limit the beneficial effects of CCs on soil health (Obour et al., 2021). Soil BD, NO<sub>3</sub>-N, and P concentrations, and WEF were unaffected by fallow management treatments in the 0-2 or 2-6 in soil depths (Table 1). However, SOC stocks were greater with grazed CCs compared to fallow or standing

CCs in the 0-2 and 2-6 in soil depths. In the 0-2 in soil depth, SOC stocks with hayed CCs were greater than standing CCs but similar to fallow, which was similar to standing CCs (Table 1). In the 2-6 in soil depth, SOC stocks with hayed and standing CCs were similar to fallow, and all were less than those of grazed CCs. In the 0-2 in soil depth, MWD with grazed CCs was similar to fallow and standing CCs but greater than hayed CCs. The MWD in the 2-6 in soil depth was unaffected by fallow management. Based on the findings of the present study, we propose careful management to maintain adequate CC residue when using CCs for forage to meet soil conservation goals.

## CONCLUSION

Results from this six-year study showed that post-wheat CCs produced about 2850 lb ac<sup>-1</sup> of total biomass on average. Still, biomass production was variable, with a significant risk of failed stand establishment. Grazing maintained about 60% of the available forage while haying maintained only about 20%. Grain sorghum yields were reduced 14% following CCs compared to fallow. However, average net returns with grazed or hayed CCs were similar to fallow and greater than standing CCs. Bulk density, NO<sub>3</sub>-N, P, and WEF were unaffected by fallow management, but grazed CCs increased SOC stocks compared to fallow. This finding suggests a possible synergistic effect of CCs and grazing on SOC stocks. Mean weight diameter of water stable aggregates with grazed CCs was similar to fallow and greater than hayed CCs. These results suggest that integrating post-wheat CCs for grazing and haying into NT dryland cropping systems in the semi-arid CGP can intensify cropping systems and increase forage availability while maintaining profitability and soil health.

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