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Summary

Grazing or haying dual-purpose cover crops (CCs) could provide an economic benefit to offset potential lost revenue when grain crop yields are decreased after CCs in dry years. However, there is concern that removing CC biomass could limit the beneficial effects of CCs for soil health and that root-limiting soil compaction may occur with grazing on no-till (NT) fields. Occasional tillage (OT) can be used to mitigate soil compaction caused from grazing CCs. The objectives of this study were to determine dual-purpose CC management and occasional tillage (OT) effects on plant-available water (PAW), crop yields, net returns, and soil properties in an NT dryland cropping system. This study was initiated in 2015 near Brownell, KS, with CCs grown in place of fallow and either hayed, grazed, or left standing. Half of each plot was tilled with a sweep plow once every three years ahead of wheat planting while the other half remained NT. Experimental design was a split-split-plot randomized complete block with four replications with all phases of the rotation present every year. Results showed that CC biomass averaged 2,800 lb/a. Grazing removed 40% of the available forage while haying removed 70%. Profile PAW at wheat planting was greater with fallow than with CCs but unaffected by tillage. Average wheat yield was unaffected by fallow management or tillage. Net returns were in the order of grazed CCs > hayed CCs > fallow = standing CCs but were unaffected by tillage on average. Fallow management had no effect on soil bulk density, which was slightly less with OT than NT. Bulk soil and particulate organic carbon were unaffected by fallow management or tillage. However, the mean weight diameter of water-stable aggregates was greater with CCs than with fallow but unaffected by tillage. Wind-erodible fraction was unaffected by fallow management but increased with OT compared to NT. These results suggest that dual-purpose CCs can provide forage for livestock, increase soil aggregate stability, maintain average crop yields, and increase net returns in NT systems. If OT is necessary to correct root-limiting soil compaction, PAW, crop yields, net returns, and soil properties are generally unaffected compared to long-term NT.

Introduction

In semi-arid environments like the central Great Plains (CGP), annual grain crop production with growing season precipitation alone is highly erratic but can be stabilized with fallow periods to store plant available water (PAW) between crops. However, fallow is an inefficient practice with only 20 to 35% of precipitation effectively stored as PAW for future crop use. Despite the challenges with intensified grain production, growing CCs in place of fallow could be superior to alternative short-season grain crops (Obour et al., 2021a). Cover crops could enhance soil health, suppress herbicide-resistant weeds, and increase precipitation use efficiency. However, despite the benefits that CCs could provide, the costs of their establishment and potential reductions in subsequent grain yields because of reduced PAW at planting present major barriers to adoption (Obour et al., 2021a). Most species used as CCs have excellent forage nutritive value attributes and could supply high-quality forage for livestock to compensate for their production costs and potentially increase system profitability. However, one primary concern with grazing CCs in NT systems is the risk of excessive soil compaction that could suppress subsequent crop yields and may require tillage for remediation (Obour et al., 2021b). If root-limiting compaction occurs, one solution could be occasional tillage (OT) to strategically ameliorate compaction, after which the cropping system would return to NT. Additionally, there is concern that biomass removal with dual-purpose CCs could limit the beneficial effects of CCs for soil health (Obour et al., 2021a). Without enough information currently available, the objectives of this study were to determine the effects of dual-purpose CC management and OT on PAW, grain crop yields, net returns, as well as soil chemical and physical properties in an NT dryland winter wheat (*Triticum aestivum* L.)–grain sorghum (*Sorghum bicolor* Moench.)–fallow (WSF) cropping system.

Procedures

This study was established in 2015 at the Kansas State University Hearting Beason (HB) Ranch near Brownell, KS (38°38′23″ N, 99°44′45″ W), to investigate best management strategies for CCs to replace fallow in the dryland cropping systems of the semi-arid central Great Plains. Long-term average (30 years) annual precipitation at the study site was 22 inches. The study design was a split-plot randomized complete block with four replications. Crop phase was the main plot and split-plots were oat (*Avena sativa* L.)–triticale (× *Triticosecale* Wittm.) CCs grown during the fallow phase of the WSF rotation. Cover crops were managed as standing cover, hayed, or grazed and were compared with NT fallow for four treatments. In 2018, the study was modified with each split-plot split again into NT and OT split-split plots to evaluate possible interactions between CC management and tillage for eight treatments. All crop phases (wheat, sorghum, or fallow) of this WSF rotation were present.

Each year, wheat was planted in October using an NT drill at 60 lb/a and harvested the following year in July. Following an 11-month fallow period, sorghum was planted at 35,000 seeds/a in June and harvested in November. Cover crops were planted in March at a seeding rate of 32 and 38 lb/a for oat and triticale, respectively, and were hayed, grazed, and chemically terminated by June. Cover crops were grazed with yearling heifers (*Bos taurus*) at densities from 780 to 1,550 lb/a on a live weight (LW) basis for 4 to 7 days in fenced paddocks across the four replications of this study. This approach required stocking densities be adjusted and grazing be delayed relative to what can be obtained by producers in the region (30 grazing days at 542 lb/a LW) to balance forage accumulation and removal on the 5.4 acres available for grazing in the study area. On or within one week following the last day of grazing, hayed CCs were harvested at a 6-inch cutting height using a small plot forage harvester (Carter Manufacturing Company). Cover crops were then chemically terminated within one week following hay harvest.

Beginning in 2018, split-plots were divided into split-split-plots of NT and OT. Every year, OT was accomplished by tilling once in July or August following CC termination prior to wheat planting to a depth of 3 inches with a Premier Tillage Minimizer sweep plow (Premier Tillage, Inc, Quinter, KS, USA).

Each year before grazing was initiated, available CC biomass was determined for the grazing treatment by hand-clipping, to the ground level, two areas of 2 × 3 ft per plot. Samples were dried at 122˚F for a minimum of 48 hr in a forced-air oven and weighed to determine dry matter. After grazing, each plot was resampled as previously described. Standing CCs were sampled similarly immediately prior to termination. Hayed CCs were harvested to a height of 6 inches with a small plot forage harvester from a strip of 3 × 100 ft in the middle of each plot. Fresh weights were recorded, subsamples collected and weighed, and then oven-dried to determine hay yield. Profile PAW (0 to 4 ft) at wheat planting was determined gravimetrically each year in September using a hydraulic probe (Giddings Machine Company). Gravimetric water contents were converted to volumetric water content (VWC) using bulk density (BD). The equivalent depth of PAW was calculated as VWC minus permanent wilting point (−1.5 bars matric potential) water content multiplied by the thickness of the soil layer.

Wheat and sorghum yields were determined each year by harvesting an area 3 × 100 ft from the center of each plot using a Massey Ferguson 8XP small-plot combine harvester (Massey Ferguson, Duluth, GA, USA), and yields were adjusted to 13.5% moisture content. Exceptional drought conditions resulted in failed crops in 2022 and 2023. Net returns were calculated for the fallow/CC and wheat phases of the cropping system as total fallow/CC and wheat revenue minus total fallow/CC and wheat costs for each treatment and year. Estimates of current field operations and input costs used 5-year average custom rate values published by Kansas State University Land Use Survey Program and the Kansas Department of Agriculture (AgManager, 2021). Wheat grain and cool-season grass hay prices were taken from USDA Economic Research Services market reports (USDA ERS, 2021). Grazing lease rates were valued based on estimated grazing days as a factor of available forage and prices published by Iowa State University Ag Decision Maker (Hofstrand & Edwards, 2015).

Soil samples were collected from the 0- to 2- and 2- to 6-inch soil depth in fall 2021 and fall 2022 following the termination of CCs and implementation of tillage. Soil BD was determined as mass of oven-dried soil divided by volume of the core following oven drying at 221°F for 48 hr. The SOC and particulate organic carbon (POC, >53 μm) concentrations were determined by loss-on-ignition, and carbon masses were calculated as concentrations multiplied by BD and the thickness of the soil layer. Lastly, intact soils samples were carefully collected with a flat shovel and were allowed to air-dry and then gently passed through a 0.75-in sieve. Subsamples of <0.31-inch diameter aggregates were obtained and used to estimate mean weight diameter (MWD) of water stable aggregates (WSA) by the wet-sieving method. The remaining sample was used to estimate wind-erodible fraction (WEF) (<0.03-in) by the dry-sieving method. Analyses of CC biomass, grain yields, net returns, as well as soil chemical and physical properties were performed using the PROC GLIMMIX procedure in SAS ver. 9.4.

Results and Discussion

On average, CC biomass remaining after grazing and haying was 61 and 30% of the standing CC, respectively, and CC biomass remaining after haying was 51% of that remaining after grazing (Table 1). Across years, CC biomass remaining after grazing was greater than that after haying in three years and similar in the remaining five years of the study. On average, PAW was not different between standing, hayed, and grazed CCs but all CCs decreased PAW by 19% compared to fallow (Table 1). Profile PAW was unaffected by tillage. Interestingly, despite reduced average PAW, average wheat yields were not different among fallow management treatments (Table 1). Yields following grazed CCs or hayed CCs were less than fallow in four and two years, respectively, but yields were never different than those following standing CCs. Wheat yields were unaffected by tillage, which suggests that OT was not required because no yield-limiting compaction occurred with grazing in the present study. Even when subsequent crop yields are reduced after dual-purpose CCs, the diversification of income streams could facilitate increased net profit (Obour et al., 2021a). On average, net returns across fallow management were in the order of grazed CCs > hayed CCs > fallow = standing CCs (Table 1). Net returns with grazed CCs were greater than all other treatments in three years and comparable to hayed CCs in five years. Hayed CCs provided net returns greater than fallow or standing CCs in all years. Net returns with standing CCs were comparable to fallow in five years, less than fallow in two years, and greater than fallow in one year. Net returns were unaffected by tillage.

A primary concern with the adoption of dual-purpose CCs is that removing CC biomass could limit the beneficial effects of CCs for soil health (Obour et al., 2021a). Additionally, grazing CCs in NT systems brings risk of soil compaction from animal hoof action, which could suppress crop yields and require tillage for remediation (Obour et al., 2021b). The SOC and POC were unaffected by fallow management or tillage (Table 2). Similarly, soil BD was unaffected by fallow management, but OT had 5% lower BD than NT. The MWD of WSA was not different between standing, hayed, and grazed CCs and was unaffected by tillage (Table 2). However, all CCs increased MWD by 37% compared to fallow. The WEF was unaffected by fallow management and was not different across tillage in one year but was 17% greater with OT than NT in the other year (Table 2). This suggests that if OT is necessary in long-term NT systems, soil properties are generally not affected compared to NT, but OT could increase WEF.

Conclusion

Results from this study showed that CC biomass production averaged about 2,800 lb/a and grazing and haying CCs removed about 40% and 70% of the available forage, respectively. Profile PAW at wheat planting was less following CCs compared to fallow. However, average wheat yields were unaffected by fallow management though the effects on wheat yields varied across years. Average net returns were in the order of grazed CCs > hayed CCs > fallow = standing CCs. Fallow management had no effect on BD, SOC, POC, or WEF, but MWD was greater with CCs than fallow. Tillage had no effect on PAW, crop yield, or net returns. Bulk density was slightly lower and WEF was slightly higher with OT than NT, but SOC, POC, and MWD were unaffected by tillage. These results suggest that dual-purpose CCs can provide forage for livestock, increase the soil aggregate stability, maintain average crop yields, and increase net returns in NT systems. If OT is necessary to correct root-limiting soil compaction, the

PAW, crop yields, net returns, and soil properties are generally unaffected compared to long-term NT.

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Table 1. Cover crop biomass remaining after grazing, haying, and chemical termination as well as fallow management and tillage effects on profile plant available water (PAW) at wheat planting, wheat yields, and net returns from 2015 to 2023 near Brownell, KS. Exceptional drought conditions in 2023 resulted in crop failures.

Treatments	Cover crop biomass	Profile PAW	Wheat yield	Net returns
	lb/a	inches	bu/a	US$/a
Fallow management				
Fallow	-	4.3a	49.2a	-15.44c
Standing cover crops	2769a[†]	3.6b	44.4a	-24.60c
Hayed cover crops	825c	3.5b	46.0a	58.87b
Grazed cover crops	1630b	3.5b	44.2a	88.500a
Tillage				
No-tillage	-	4.0a	47.6a	14.92a
Occasional tillage	-	4.0a	47.9a	4.02a
Year				
2015-2016	2724a	3.9b	57.0a	117.68a
2016-2017	1542cd	4.1b	37.1d	19.22d
2017-2018	2228ab	2.1c	36.5d	30.43cd
2018-2019	2002bc	5.3a	47.7bc	59.73b
2019-2020	1986bc	5.3a	47.1bc	41.44bcd
2020-2021	1304cd	3.5b	52.0ab	49.85bc
2021-2022	10474d	-	44.8c	16.66d
2022-2023	1102d	2.0c	-	-120.33e
Type III test of fixed effects				
Fallow management (M)	<0.0001	0.0179	0.1039	<0.0001
Till (T)	<0.0001	0.7367	0.6829	0.0908
M × Y	<0.0001	0.8850	0.7959	0.8730
Year (Y)	-	<0.0001	<0.0001	<0.0001
M × Y	-	0.0954	0.0051	<0.0001
T × Y	-	0.6354	0.2788	0.0902
M × T × Y	-	0.4912	0.6152	0.1586

[†]Means followed by the same letter within the same column are not significantly different ($\alpha = 0.05$) among treatments.

Table 2. Fallow management and tillage effects on soil organic carbon (SOC), particulate organic carbon (POC), bulk density (BD), mean weight diameter (MWD) of water stable aggregates, and wind erodible fraction (WEF) in the 0-2 inch soil depth at wheat planting in 2021 and 2022 near Brownell, KS

Treatments	SOC	POC	BD	MWD	WEF
	---------- tons/a ----------		lb/ft^3	inch	%
Fallow management					
Fallow	4.16a†	1.54a	76.2a	0.03b	27.9a
Standing cover crops	4.39a	1.76a	78.0a	0.04a	28.5a
Hayed cover crops	4.30a	1.85a	77.4a	0.04a	30.5a
Grazed cover crops	4.30a	1.68a	76.2a	0.04a	29.1a
Tillage					
No-tillage	4.40a	1.80a	78.7a	0.04a	27.8a
Occasional tillage	4.17a	1.61a	74.9b	0.04a	30.2a
Year					
2021	3.85b	1.43b	72.4b	0.04a	23.8b
2022	4.73a	1.98a	81.8a	0.03a	34.2a
Type III test of fixed effects					
Fallow management (M)	0.7140	0.3135	0.8509	0.0291	0.4063
TILL (T)	0.2258	0.2421	0.0427	0.6555	0.1994
M × Y	0.5611	0.4389	0.1491	0.3692	0.1532
Year (Y)	0.0455	0.0451	0.0246	0.2265	0.0107
M × Y	0.6583	0.3400	0.6080	0.2588	0.6018
T × Y	0.3697	0.9244	0.8522	0.8673	0.0483
M × T × Y	0.3491	0.0611	0.7450	0.6775	0.3533

†Means followed by the same letter within the same column are not significantly different ($\alpha = 0.05$) among treatments.