NITROGEN DYNAMICS AND AGRONOMIC-ENVIRONMENTAL IMPACTS OF ANNUAL VS. PERENNIAL COVER CROPS IN IRRIGATED CORN-SOYBEAN SYSTEMS ON SANDY SOILS

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ABSTRACT

Irrigated sandy soils can be highly productive yet vulnerable to Nitrogen (N) losses. Kura Clover (*Trifolium ambiguum*) living mulch offers an alternative mitigation strategy. However, there is limited research aiming to holistically compare the effect of annual vs. perennial cover crops on season-long N dynamics and agronomic-environmental impacts on corn (*Zea Mays* L.)-soybean [*Glycine max* (L.) Merr.] cropping systems. This 2-yr study assessed rye (*Secale cereale)* and Kura effects on corn and soybean grain yield, season-long N availability and uptake, nitrate (NO_3^--N) leaching, ammonia (NH_3-N) volatilization, and nitrous oxide (N_2O-N) emissions in continuous corn (CC), corn-soybean (CSb), and soybean-corn (SbC) cropping systems on irrigated sandy soil. Treatments included 3 cover strategies (no cover, annual rye, and Kura clover living mulch) paired with five N rates (0-270 lb N ac^{-1} in CC and CSb) for no cover and rye, and two N rates (0 and 180 lb N ha^{-1} in CSb or 225 lb N ha^{-1} in CC) for Kura. Rye and no cover showed similar yield and N uptake across cropping systems. Kura decreased CSb yield by 28% and impacted N uptake. In CC, wetter conditions during grain filling diluted Kura's yield penalties and had no impact on N uptake throughout. N availability up to V6 impacted corn the most, exacerbating CSb sensitivity due to Kura's competition for soybean N credits. Kura reduced NO_3^--N losses by 42% compared to rye and no cover. Contrastingly, Kura increased NH_3-N volatilization by 13 and 20% in CSb and SbC, respectively. Both cover crops had no effect on N_2O-N emissions. Kura clover in CC demonstrated a promising agronomic performance while offering synergistic agroecosystem services.

INTRODUCTION

The State of Minnesota has approximately 240,000 acres of irrigated sandy soils which are predominantly under corn and soybean cultivation. A critical aspect to ensure productivity optimization of these soils is through the efficient supply of nitrogen. However, N recovery from the corn plant typically ranges between 30-50% in the Midwest region, suggesting significant N losses via NO_3^--N leaching, NH_3-N volatilization, N_2O-N emissions or soil immobilization/fixation. One mitigation practice that has gained traction is the use of cover crops, often promoted as a signature tool for achieving sustainable cropping systems. Due to the need of winter-hardy species in the Upper Midwest and its relatively easy integration to corn and soybean systems, rye is considered the staple cover crop in the region. Nonetheless, unperceived or antagonistic results have been observed from the use of rye. Within the US Midwest, another factor hindering adoption rates is the narrow window between fall harvest and winter, along with the added cost of annually planting a second crop. Thus, living mulches are being considered as an alternative to rye cover crop systems. Kura has been recently promoted as a potentially viable living mulch due to its winter hardiness, spreading habit, and N fixation capability.

Variable outcomes from implementing Kura clover suggest attractive environmental benefits, but variable impacts on productivity. Cover crops influence soil N availability for the main crop, which can significantly impact the agronomical and environmental output of a system. There is a critical need of holistically understanding how Kura clover living mulch affects N dynamics throughout the growing season compared to the commonly used annual rye cover crop. These insights can facilitate both productive and environmentally optimized N management strategies in irrigated sandy soils. Therefore, the objectives of this study were to determine the effects of annual rye cover crop and Kura clover living mulch on N dynamics and its impact on the agronomic and environmental performance of CC, CSb, and SbC cropping systems.

MATERIALS AND METHODS

The study was located at the Rosholt Research Farm in Westport, MN and was conducted from September 2019 to October 2022. The site was divided into three adjacent blocks to accommodate three cropping systems: one block with CC and two blocks that alternated a CSb and a SbC rotation, with both crops present each year. Each of the cropping systems allocated a randomized complete block design with 12 treatments replicated 4 times. Irrigation was applied uniformly with a linear movement system and was planned via the checkbook scheduling method. Treatments factorially combined 3 cover management approaches (no cover, spring-terminated rye, and Kura clover as a living mulch) with 5 N rates for no cover and rye, and 2 N rates for Kura clover. No cover and rye included 0, 90, 180, 225, and 270 lb N ac^{-1} rates in both CC and CSb, whereas Kura clover received 0 and 225 lb N ac^{-1} in CC, and 0 and 180 lb N ha^{-1} in CSb. The SbC rotation did not receive any nitrogen. Urea (46-0-0) with Agrotain [N-(n-butyl) triophosphoric tiramide] was used as the fertilizer source. The N fertilizer was broadcast in the no cover and rye plots and banded by the corn row in Kura plots to minimize N uptake by kura. The fertilization was completed in 3 split-applied events when the corn reached the V2, V6, and V10 growth stages with a corresponding 25, 25, and 50% of the total N rate for each treatment.

Cover crops were sampled for aboveground biomass prior to corn and soybean planting. A whole plant sampling was performed on the corn and soybean when they reached R6. Subsequently, the dried plant biomass was analyzed to determine total N concentration via dry combustion. Corn grain collected at the R6 stage was added to the weight of the combine-harvested dataset for calculation of total grain yield. Four pairs of Plant Root Simulator (PRS) probes were inserted into the soil at a depth of 6 in for 3-week intervals, during seven measurement periods to quantify season-long N fluxes. A total of 216 permanently installed lysimeters facilitated weekly water sampling to determine NO_3^--N concentrations. Drainage was calculated via the water balance equation using parameters established by the FAO Irrigation and Drainage paper 56. The product of both was used to calculate NO_3^--N loads. Nitrous oxide emissions were measured weekly at a decreasing frequency as the season progressed using a portable high-accuracy AERIS N_2O/CO gas analyzer. An open chamber with PTFE moisture barrier acid trap was used to quantify NH_3-N volatilization 1, 4, 7, 14, 21, and 28 days after each split-fertilization event. An ANOVA and mean separation (when applicable) were conducted for all variables in SAS 9.4, while N_2O-N fluxes were calculated in R studio.

RESULTS AND DISCUSSION

Only 2021 depicted significant differences for both cover crop biomass and N content. These interactions were mainly driven by a consistent decrease in rye biomass at the N fertilized rate. This antagonistic response was explained by the residue source and accumulation intensity from the previous year which impacted the subsequent cover crop growth and development. This pattern is evidenced with CSb (rye planted on soybean stubble) resulting in approximately 3x more biomass accumulation across cover crops compared to CC and SbC (Table 1).

Table 1. Cover crop biomass and N content from continuous corn (CC), corn-soybean (CSb), and soybean-corn (SbC) as affected by Cover and N rates.

		2021			2022		
Cover Crop	**N Rate**	**CC**	**CSb**	**SbC**	**CC**	**CSb**	**SbC**
				Biomass			
	lb N acre	------------------------		**lb acre^{-1}**		------------------------	
Kura	0	67 A	233 AB	64 A	164	246	318
Kura	180/225	94 AB	349 A	56 A	203	208	343
Rye	0	122 B	292 AB	151 B	222	177	235
Rye	180/225	64 A	152 B	70 A	182	262	274
				N Content			
		------------------------		**lb acre^{-1}**		------------------------	
Kura	0	1.94 A	7.38	1.95	5.72	7.53	10.51
Kura	180/225	2.87 B	11.40	2.24	8.10	7.98	11.22
Rye	0	2.21 A	5.32	2.56	3.64	3.47	4.37
Rye	180/225	1.18 A	3.37	1.53	4.22	6.05	3.37

Means within a year and column followed by the same letter are not significantly different ($P<0.05$). 180/225: In the CC system a 225 lb N acre^{-1} rate was applied whereas in CSb a 180 lb N acre^{-1} was applied.

Rye consistently resulted in similar grain yields than no cover across N rates in both corn rotations and years. Conversely, in CSb Kura clover led to an average yield decrease of 28% across N rates. The negative effect of Kura clover on CSb grain yield had a lesser impact on CC, as evidenced on a lack of significant differences by cover in 2021 and an interaction of the main effects in 2022, were Kura decreased corn grain yield only when fertilized. The grain yield response observed in CC is likely the combined effect from yearly precipitation variability with a reduced competition from Kura clover. Moreover, for SbC the cover main effect was significant only in 2022, indicating a 21% yield decrease caused by Kura compared to no cover and rye (Table 2). As expected, N uptake across cropping systems and years had a similar response to grain yield. More importantly, the lack of differences by cover in CC also suggests that it is possible to synergistically implement Kura clover living mulch within this production system without compromising corn N uptake.

Table 2. Grain yield and N uptake averaged across Cover and N rate main effects from continuous corn (CC), corn-soybean (CSb), and soybean-corn (SbC) cropping systems.

Main Effects	2021			2022		
	CC	CSb	SbC	CC	CSb	SbC
				Grain Yield		
Cover Effect			------------------------ bu acre^{-1} ------------------------			
No Cover	104	144 A	59	100	126 A	65 A
Rye	101	143 A	55	99	135 A	61 AB
Kura	104	103 B	61	81	94 B	50 B
N Rate Effect						
0	51	86	57	51	79	57
180/225	155	174	60	136	157	60
				N Uptake		
Cover Effect			------------------------ lb acre^{-1} ------------------------			
No Cover	90	109 A	399	92	101 A	346 A
Rye	84	103 A	408	93	103 A	337 A
Kura	85	82 B	415	82	84 B	263 B
N Rate Effect						
0	39	58 A	389	47	58	311
180/225	134	139 B	425	131	134	319

Means within a year and column followed by the same letter are not significantly different ($P<0.05$). 180/225: In the CC system a 225 lb N acre^{-1} rate was applied whereas in CSb a 180 lb N acre^{-1} was applied.

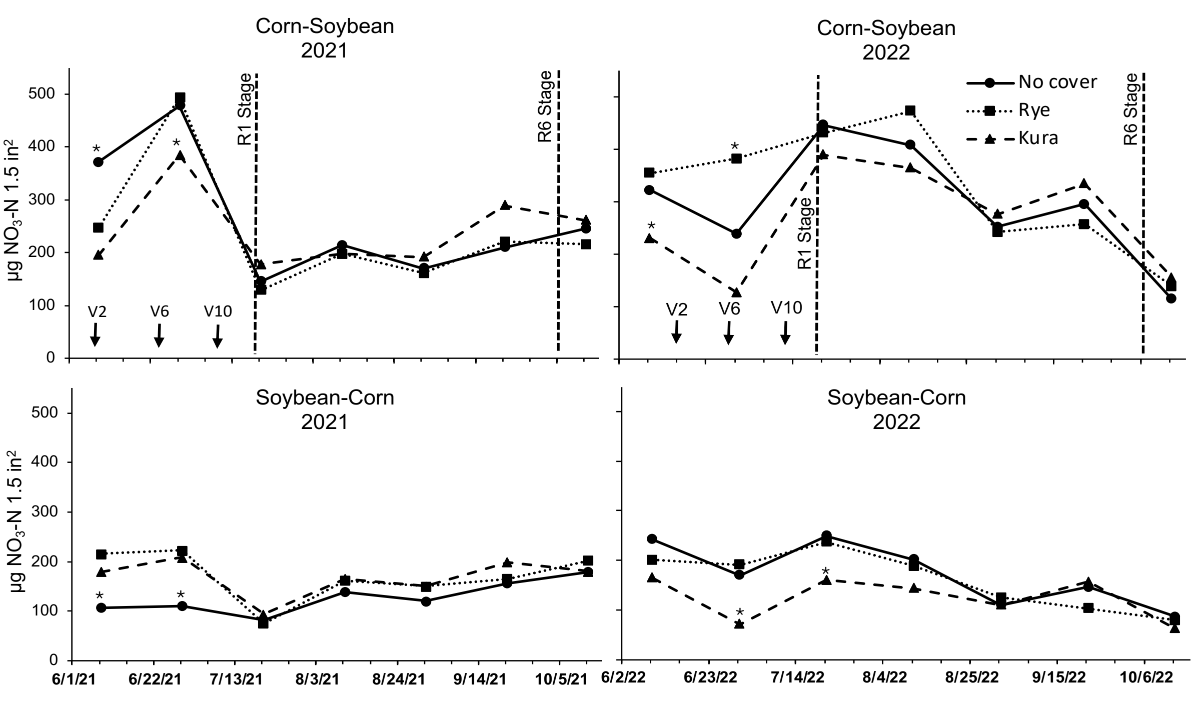

Figure 1. Mean bioavailable NO_3^--N measured by PRS probes showing the season-long Cover effect for CSb and SbC cropping systems averaged across N rates. Asterisks indicate significant differences between treatments at a time interval ($P<0.05$). Arrows indicate timing of the split-fertilization events at corresponding corn development stages.

The CSb rotation resulted in a similar response during both years showing cover crops differences only in the first 2 PRS timings were Kura had the lowest NO_3^--N fluxes compared to no cover and rye. Contrastingly, the absence of differences between covers throughout timings 3 to 7 indicate that the Kura Clover yield penalty in CSb was mainly caused by a decrease of early-season N availability. Earlier stages of SbC development were also more sensitive to soil N availability reductions from Kura, as evidenced in the yield performance in 2022 (Figure 1).

The major environmental loss observed was via NO_3^--N leaching. Although differences were not as evident on the concentration between cover crops, factoring in the drainage facilitated an improved understanding of the system. Kura tended to reduce losses in most scenarios, particularly when fertilized. However, this effect was only significant in 2022 on the corn systems were Kura reduced NO_3^--N load by 42% on average compared to rye and no cover (Table 3). There is also a potential under-quantification of Kura's benefits in 2021 due to current limitations on inter-cropping water usage modeling particularly as the growing season progresses. In addition, the three cropping systems depicted a significant response to N fertilizer ($P<0.05$).

Table 3. Season long NO_3^--N concentrations and cumulative load from continuous corn (CC), corn-soybean (CSb), and soybean-corn (SbC) as affected by Cover and N rates.

Crop	N Rate	2021			2022		
		No Cover	Rye	Kura	No Cover	Rye	Kura
		Season-long Nitrate Concentration					
	lb N acre	------------------------ mg NO_3^--N L^{-1} ------------------------					
CC	0	5	6	9	5	6	11
	225	27	29	34	24	23	25
CSb	0	11	13	13	16 A	19 B	13 A
	180	18	20	24	17 A	23 B	18 A
SbC	0	13	13	12	11	11	10
	180	25	27	27	30	27	27
		Cumulative Nitrate Load					
		------------------------ lb NO_3^--N $acre^{-1}$ ------------------------					
CC	0	16	25	31	16 A	16 A	22 A
	225	64	68	44	35 B	27 B	19 C
CSb	0	38	45	34	44 A	42 A	24 B
	180	44	43	46	25 A	26 A	13 B
SbC	0	51	55	38	24	20	12
	180	93	97	80	56	52	36

Means within a year and row followed by the same letter are not significantly different. 180/225: In the CC system a 225 lb N acre^{-1} rate was applied whereas in CSb a 180 lb N acre^{-1} was applied.

The smaller fraction of environmental losses corresponded to gas emissions where CC was unaffected by cover crops. Further, Kura increased cumulative NH_3-N volatilization by 13 and 20% in CSb and SbC, respectively. This can likely be a result of the growing conditions derived from the living mulch growing system, such as greater moisture retention or changes in soil pH due to N_2 fixation leading to higher volatilization activity. Cover crops did not significantly affect cumulative N_2O-N emissions although effect trends were observed from Kura but were likely negligible due to the high variability of N_2O-N measurements.

Table 4. Cumulative NH_3-N volatilization and N_2O-N emissions from continuous corn (CC), corn-soybean (CSb), and soybean-corn (SbC) as affected by Cover and N rates.

Rotation		**2021**			**2022**		
	N Rate	**No Cover**	**Rye**	**Kura**	**No Cover**	**Rye**	**Kura**
		Cumulative Ammonia VolatilizationΨ					
	lb N acre	~~~~~~~lb NH_3-N acre^{-1}~~~~~~~					
CC	0	1.29	1.42	1.56	1.61	1.74	1.85
	225	1.53	1.56	1.37	1.66	1.59	1.86
CSb	0	1.17 A	1.11 A	1.30 B	1.54	1.13	1.78
	180	1.20 A	1.04 A	1.30 B	1.50	1.36	1.41
SbC	0	1.18 A	1.11 A	1.40 B	1.66 A	1.36 A	1.29 A
	180	1.27 A	1.25 A	1.10 A	1.38 A	1.34 A	1.84 B
		Cumulative Nitrous Oxide Emissions					
	lb N acre	~~~~~~~lb N_2O-N acre^{-1}~~~~~~~					
CC	0	0.42	0.21	0.35	0.16	0.12	0.10
	225	0.49	0.84	0.52	0.69	0.65	0.67
CSb	0	0.24	0.37	0.08	0.07	0.32	0.28
	180	0.77	0.67	0.26	0.74	0.94	1.40
SbC	180	0.30	0.22	0.17	0.12	0.07	0.16

180/225 In the CC system, a 225 lb N acre^{-1} rate was applied whereas in CSb a 180 lb N acre^{-1} was applied.

Ψ Cumulative NH_3-N was a period of 77 and 84 days for 2021 and 2022, respectively.