

Table S1. Primer pairs and PCR conditions for quantitative PCR

Target genes	Primer	Sequence (5'-3')	Amplification efficiency (R2 > 0.99) (%)	References
AOA- <i>amoA</i>	Arch-amoA26F	STAATGGTCTGGCTTAGACG	96.10	(Wang et al., 2019)
	Arch-amoA417R	GCGGCCATCCATCTGTATGT		
AOB- <i>amoA</i>	amoB-1F	GGGGTTTCTACTGGTGGT	94.90	(Wang et al., 2019)
	amoB-2R	CCCCTCKGSAAAGCCTTCTTC		
<i>nirS</i>	cd3aF	GTSAACGTSAAGGARACSGG	92.35	(Shi et al., 2019)
	R3cdR	GASTTCGGRTGSGTCTTGA		
<i>nirK</i>	nirKF1aCu	ATCATGGTSCTGCCGCG	92.70	(Shi et al., 2019)
	nirKR3Cu	GCCTCGATCAGRTTGTGGTT		
<i>narG</i>	narG-1960m2f	TAYGTSGGGCAGGARAACTG	91.64	(Di et al., 2014)
	narG-2050m2r	CGTAGAAGAAGCTGGTGCTGTT		
<i>nosZ</i>	nosZ-1126F	GGGCTBGGGCCRTTGCA	87.60	(Wang et al., 2022)
	nosZ-1381R	GAAGCGRTCCTTSGARAACTTG		

Table S2. Dry matter yield of different winter cover crops on 2021

Treatment	Aboveground biomass (kg ha ⁻¹)	Undergroundbiomass (kg ha ⁻¹)	Total biomass (kg ha ⁻¹)
FW	1050±16.51c	263±3.68c	1312±11.02c
RrG	3301±19.67b	2250±31.56a	5551±18.84b
OrV	4752±27.25a	1900±13.66a	6653±32.13a
VvR	3801±23.44b	1190±21.94b	4991±10.35b

Note: Different lowercase letters indicate significant differences among different cover crops ($n = 3$, $P < 0.05$).

Table S3. Effects of long-term cover crops on soil moisture in the soil profile.

Depth(cm)	FW	RrG	VvR	OrV
10	0.33±0.02b	0.39±0.00a	0.32±0.02b	0.42±0.01a
20	0.34±0.01b	0.36±0.01b	0.37±0.02ab	0.40±0.00a
30	0.33±0.01b	0.37±0.01a	0.33±0.01b	0.39±0.00a
40	0.33±0.01b	0.36±0.01ab	0.33±0.02b	0.39±0.01a
50	0.30±0.00c	0.34±0.01b	0.33±0.02bc	0.40±0.01a
60	0.30±0.00b	0.31±0.01b	0.31±0.02b	0.36±0.01a
70	0.29±0.00b	0.29±0.01b	0.25±0.00c	0.35±0.01a
80	0.26±0.01c	0.27±0.01bc	0.29±0.01b	0.34±0.01a
90	0.23±0.00b	0.26±0.01b	0.24±0.00b	0.33±0.00a
100	0.24±0.01b	0.29±0.01a	0.28±0.01a	0.29±0.01a
120	0.23±0.01b	0.25±0.01b	0.23±0.01b	0.30±0.01a
140	0.16±0.00b	0.25±0.01a	0.27±0.01a	0.28±0.00a
160	0.18±0.01a	0.19±0.01a	0.19±0.02a	0.20±0.01a
180	0.20±0.03b	0.19±0.01b	0.26±0.01a	0.22±0.02b
200	0.22±0.04b	0.24±0.01ab	0.26±0.01a	0.25±0.03ab

Results are reported as means ± SD (n = 3). Different letters within a row indicate significant differences between the treatments by LSD-Test least significant difference ($p<0.05$).

Table S4. Effects of long-term cover crops on NO₃⁻N content in the soil profile.

	Depth (cm)	FW	RrG	VvR	OrV
NO ₃ ⁻ -N	10	14.51±1.46c	21.11±3.49b	27.66±1.92a	15.69±1.71c
	20	6.83±1.16c	16.17±0.42a	10.79±0.26b	10.54±0.66b
	30	5.83±1.12a	6.02±1.64a	6.80±0.53a	6.33±1.31a
	40	4.85±0.49a	5.98±1.01a	5.99±0.53a	5.15±0.55a
	50	6.18±1.00a	6.68±1.28a	7.29±0.63a	4.74±0.40a
	60	7.84±1.52a	7.20±1.02a	7.61±0.80a	6.04±0.29a
	70	7.60±1.09ab	7.89±1.64ab	9.46±1.12a	5.60±0.74b
	80	8.77±0.31a	7.91±0.24a	7.30±0.59ab	5.10±0.07b
	90	8.27±0.36a	6.50±1.00a	7.07±1.00a	5.66±0.30a
	100	9.14±0.28a	5.25±0.85b	6.94±0.68ab	6.74±1.44ab
	120	7.82±0.53a	5.37±0.90ab	6.62±0.50ab	4.77±0.06b
	140	6.45±0.79a	6.39±0.40a	5.04±0.21a	3.87±0.40a
	160	5.63±0.51a	4.14±0.13a	4.38±0.16a	5.93±1.87a
	180	3.91±0.35a	3.15±0.12a	4.83±1.10a	4.96±1.51a
	200	3.48±0.23a	2.74±0.14a	3.70±0.63a	3.53±0.39a

Results are reported as means ± SD (n = 3). Different letters within a row indicate significant differences between the treatments by LSD-Test least significant difference ($p < 0.05$).

Table S5. Effects of long-term cover crops on total nitrogen content in the soil profile.

	Depth(cm)	FW	RrG	VvR	OrV
TN	10	1.42±0.05b	1.63±0.01a	1.52±0.04ab	1.64±0.03a
	20	1.20±0.02bc	1.42±0.01a	1.16±0.05c	1.31±0.01ab
	30	1.02±0.03b	1.03±0.04b	1.21±0.01a	1.05±0.03b
	40	0.57±0.00c	0.89±0.04b	1.10±0.03a	0.88±0.04b
	50	0.78±0.05b	1.03±0.02a	1.12±0.05a	1.07±0.00a
	60	1.03±0.02b	1.14±0.02b	1.32±0.08a	1.12±0.04b
	70	0.98±0.03b	1.11±0.05a	1.18±0.03a	1.15±0.05a
	80	1.04±0.01b	1.20±0.05a	1.14±0.03ab	1.17±0.01a
	90	1.06±0.03a	1.17±0.02a	1.13±0.01a	1.14±0.01a
	100	1.07±0.02a	1.07±0.04a	1.13±0.03a	1.10±0.03a
	120	1.04±0.00ab	1.11±0.08a	0.96±0.02b	1.10±0.02a
	140	1.04±0.02b	1.10±0.05ab	1.21±0.18a	0.74±0.03c
	160	0.78±0.01a	0.78±0.03a	0.65±0.00b	0.86±0.01a
	180	0.85±0.03b	0.98±0.05a	1.01±0.06a	0.91±0.04ab
	200	0.82±0.01c	1.05±0.06ab	1.11±0.03a	0.99±0.03b

Results are reported as means \pm SD (n = 3). Different letters within a row indicate significant differences between the treatments by LSD-Test least significant difference ($p < 0.05$).

Table S6. Abundances of AOB-*amoA*, AOA-*amoA*, *nirS*, *narG* *nirK*, *nosZ* genes in the soils under different cover crop treatments of fallow-spring corn (FW), ryegrass-spring corn (RrG), oryochopragmus violaceus-spring corn (OrV) and hairy vetch-spring corn (VvR) .

Depth(cm)	Treatment	Gene copy numbers (copies/g dry soil)					
		AOB- <i>amoA</i>	AOA- <i>amoA</i>	<i>nirS</i>	<i>nirK</i>	<i>narG</i>	<i>nosZ</i>
10	FW	4566267±3563647a	4566267±3563647a	76348±26833a	117758±38023a	584964±96565a	21856±3324a
	RrG	1794492±870235b	1794492±870235b	33426±12855c	67891±20598b	469600±243148ab	22068±13421a
	OrV	2294648±1311140b	2294648±1311140b	32402±11395c	51535±28390b	424309±60621b	26464±265a
	VvR	2694243±2012945b	2694243±2012945b	51233±5430b	54439±16137b	534524±23481ab	25794±13253a
30	FW	955869±598919a	955869±598919a	14191±4102b	77243±15888a	135067±57539a	11300±1058b
	RrG	644091±166994a	644091±166994a	15037±7404b	51419±14395b	258683±156655a	11912±6487ab
	OrV	1011870±422380a	1011870±422380a	25878±6838ab	63776±9138ab	271510±27638a	19527±943a
	VvR	930769±840097a	930769±840097a	30906±7569a	39895±6673b	243358±219860a	9304±3186b
	FW	484371±110531a	484371±110531a	8880±5055a	31579±14490a	76210±52071a	2671±1507b

60	RrG	401260±100005a	401260±100005a	15174±6287a	43995±5916a	112795±139280a	11618±9880a
	OrV	423383±52917a	423383±52917a	13706±2724a	33897±9821a	69980±24380a	4256±1059ab
	VvR	554498±342966a	554498±342966a	21812±10144a	38730±1251a	93103±37887a	10554±3048ab
100	FW	517157±171947a	517157±171947a	10699±7248a	31988±31354a	59175±48535a	3430±1396a
	RrG	482449±30879a	482449±30879a	17829±5200a	20580±5089a	36337±11581a	1966±1119a
	OrV	559911±116193a	559911±116193a	10258±3058a	13696±3712a	61625±79129a	3187±2356a
	VvR	314986±79846a	314986±79846a	13695±10983a	18114±13753a	50501±31393a	2380±2093a
140	FW	443813±3045a	443813±3045a	10284±5913a	15360±10431a	95976±57409a	3628±3323a
	RrG	487125±39377a	487125±39377a	9204±3188a	7362±2947a	30330±23212a	948±452a
	OrV	390339±97088a	390339±97088a	7009±3400a	12483±4086a	42977±39429a	5377±4287a
	VvR	405941±258960a	405941±258960a	8570±2833a	11514±7262a	39948±30447a	2561±1000a
200	FW	468786±46545a	468786±46545a	7117±1333a	13765±4706a	27951±13730a	1802±127a
	RrG	569267±48980a	569267±48980a	8358±3807a	6625±1140a	36208±26087a	1314±390a
	OrV	508399±126247a	508399±126247a	11328±8483a	6970±1857a	24420±9778a	1226±274a
	VvR	313049±100640a	313049±100640a	9047±6393a	7126±1859a	24281±14380a	1237±110a

Note: Results are reported as means ± SD (n = 3). Different letters within a row indicate significant differences between the treatments by LSD-Test least significant difference (P<0.05).

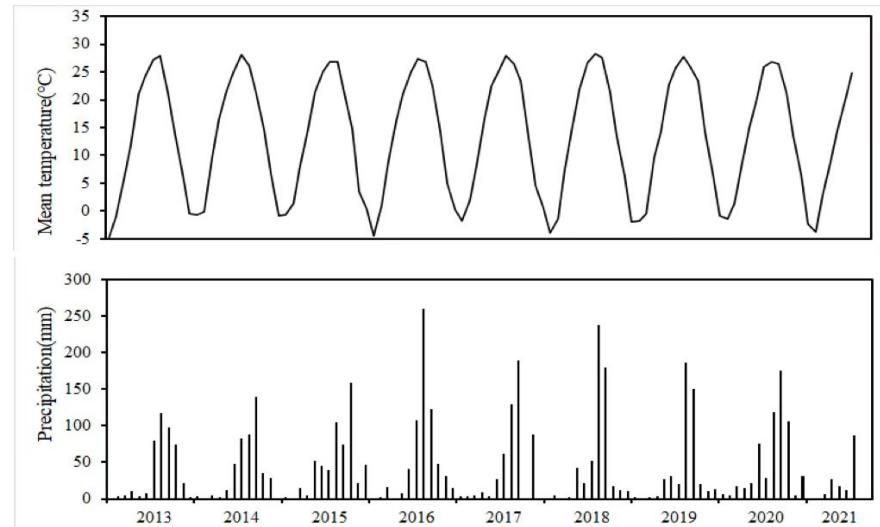


Figure S1. Mean monthly temperature and cumulative precipitation from January 2013 to May 2021 at the experimental site.

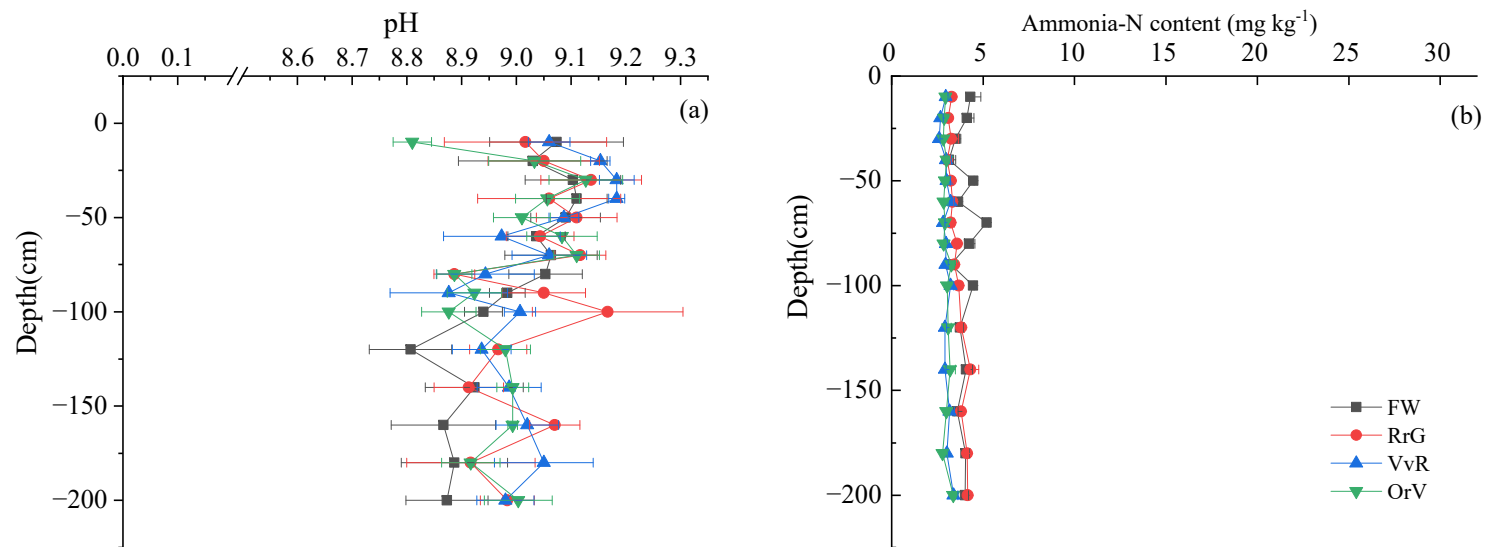


Figure S2. Effects of long-term cover crops on soil pH and ammonia-N content in the soil profile.

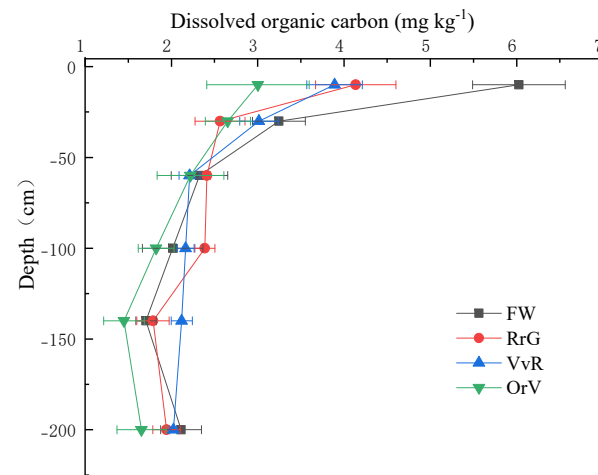


Figure S3. Effects of long-term cover crops on soil dissolved organic carbon in the soil profile.

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