Nitrous oxide emission from a Ferralsol in pigeon pea – maize rotation under conservation agriculture and biochar amendments in northern Uganda

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Supplementary material

Methodology

Table S1: Model selection and summary statistics of ANOVA for effect of rotation (conventional and convent MM) on hourly N_2O fluxes (µg m^2 h^{-1}). Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects

Models	AIC	BIC
mod1: N2Oflux ~ treatment × season × position + (1 | block) + (1 | frequency)	2364.9	2404.6
mod2: N2Oflux ~ treatment × position + (1 | block) + (1 | frequency)	**2359.3**	**2384.6**

Random effects	Variance	SD
Sampling frequency	45.44	6.741
Block	0	0
Residual	301.24	17.356

Fixed effects	χ2	df	P-value
Treatment	1471.99	1	0.03
Position	1375.06	1	0.03
Treatment × Position	1379.33	1	0.03

$$Y_{ijk} = \beta_0 + \beta_1 \cdot \text{treatment}_{ij} + \beta_2 \cdot \text{position}_{ij} + \beta_3 \cdot (\text{treatment} \times \text{position})_{ij} + u_k + v_j + \epsilon_{ijk}$$

Table S2: Model selection and summary statistics of ANOVA for effect of tillage (Conventional, CA, CA+BC) on hourly N_2O fluxes (µg m^2 h^{-1}). Variance and standard deviation (SD) are shown for the random effect and chi-square (χ2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects

Models	AIC	BIC
mod1: N2Oflux ~ treatment × season × position + (1 | block) + (1 | frequency)	3432.5	3492.7
mod2: N2Oflux ~ treatment × position + (1 | block) + (1 | frequency)	**3424.2**	**3460.3**

Random effects	Variance	SD
Sampling frequency	47.58	6.897
Block	0	0
Residual	229.57	15.152

Fixed effects	χ2	df	P-value
Treatment	2297.11	2	0.01
Position	631.92	1	0.09
Treatment × Position	2201.69	2	0.01

$$Y_{ijk} = \beta_0 + \beta_1 \cdot \text{treatment}_{ij} + \beta_2 \cdot \text{position}_{ij} + \beta_3 \cdot (\text{treatment} \times \text{position})_{ij} + u_k + v_j + \epsilon_{ijk}$$

Table S3: Model selection and summary statistics of ANOVA on effect of rotation on ammonium (mg kg^{-1}). Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects. Results are presented in Fig 2a, b.

Models	AIC	BIC
mod1: ammonium ~ treatment × season × position + (1 | block)	2538.3	2574.0
mod2: ammonium ~ treatment + season + (1 | block)	**2530.5**	**2548.4**

Random effects	Variance	SD
Block	3.854	1.963
Residual	847.086	29.105

Fixed effects	$\chi2$	df	P-value
Treatment	5214.11	1	0.01
Position	4524.97	1	0.02

$$Y_{ijk} = \beta_0 + \beta_1 \cdot \text{treatment}_j + \beta_2 \cdot \text{season}_{ij} + u_k + \epsilon_{ijk}$$

Table S4: Model selection and summary statistics of ANOVA on effect of rotation (2 treatments) on nitrate (mg kg^{-1}). Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects. Results are presented in Fig 2c, d.

Models	AIC	BIC
mod1: nitrate ~ treatment × season × position + (1 | block)	1876.6	1912.3
mod2: nitrate ~ treatment + season + (1 | block)	**1868.5**	**1886.4**

Random effects	Variance	SD
Block	0	0.000
Residual	68.64	8.285

Fixed effects	$\chi2$	df	P-value
Treatment	1.939	2	0.867
Season	150.417	1	0.139

$$Y_{ijk} = \beta_0 + \beta_1 \cdot \text{treatment}_{ij} + \beta_2 \cdot \text{season}_{ij} + u_k + \epsilon_{ijk}$$

Table S5: Model selection and summary statistics of ANOVA on effect of tillage (Conventional, CA, CA+BC) on ammonium (mg kg^{-1}). Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects. Results are presented in Fig 3a.

Models	AIC	BIC
mod1: ammonium ~ treatment × season × position + (1 | block)	3870.7	3926.5
mod2: ammonium ~ treatment + (1 | block)	**3864.5**	**3884.6**

Random effects	Variance	SD
Block	5.005	2.237
Residual	914.410	30.239

Fixed effects	$\chi2$	df	P-value
Treatment	7122.03	2	0.02

$$Y_{ijk} = \beta_0 + \beta_1 \cdot \text{treatment}_{ij} + u_k + \epsilon_{ijk}$$

Table S6: Model selection and summary statistics of ANOVA on effect of tillage on nitrate (mg kg^{-1}). Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects. Results are presented in Fig 3b.

Models	AIC	BIC
mod1: nitrate ~ treatment × season × position + (1 | block)	3373.6	3429.7
mod2: nitrate ~ treatment + (1 | block)	**3368.2**	**3388.2**

Random effects	Variance	SD
Block	0	0.000
Residual	233.7	15.29

Fixed effects	$\chi2$	df	P-value
Treatment	145.259	2	0.733

$$Y_{ijk} = \beta_0 + \beta_1 \cdot \text{treatment}_{ij} + u_k + \epsilon_{ijk}$$

Table S7: Model selection and summary statistics of ANOVA on effect of WFPS on N_2O. Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects. Results are presented in Fig 4.

Models	AIC	BIC
mod1: WFPS ~ treatment × season × position + (1 | block)	4658.5	4735.5
mod2: WFPS ~ season + (1 | block)	**4634.8**	**4651.9**

Random effects	Variance	SD
Block	0	0.000
Residual	339.2	18.42

Fixed effects	$\chi2$	df	P-value
Season	4695.465	1	0.0002

$$Y_{ijk} = \beta_0 + \beta_1 \cdot \text{treatment}_j + \beta_2 \cdot \text{season}_j + u_k + \epsilon_{ij}$$

Table S8: Model selection and summary statistics of ANOVA on effect of total mineral N on N2O. Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects. Results are presented in Fig 4.

Models	AIC	BIC
mod1: mineralN ~ treatment × season × position + (1 | block) + (1 | sampling frequency)	4861.8	4943.1
mod2: mineralN ~ treatment + (1 | block) + (1 | sampling frequency)	**4851.8**	**4881.8**

Random effects	Variance	SD
Sampling frequency	320.81	17.911
Block	10.88	3.298
Residual	451.76	21.255

Fixed effects	$\chi2$	df	P-value
Treatment	7195.94	3	0.001

$$Y_{ijk} = \beta_0 + \beta_1 \cdot \text{treatment}_j + \beta_2 \cdot \text{season}_j + u_k + \epsilon_{ij}$$

Table S9: Model selection and summary statistics of ANOVA for effect of rotation on cumulative N_2O emissions (kg N_2O-N ha^{-1}) in season one and two. Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects. Results are presented in Fig 5a, 5b, S3.

Models	AIC	BIC
mod1: cumN2O ~ treatment × season × position + (1 | block)	0.954	15.611
mod2: nitrate ~ treatment + position (1 | block)	**-3.485**	**3.843**

Random effects	Variance	SD
Block	0.003	0.061
Residual	0.036	0.189

Fixed effects	$\chi2$	df	P-value
Treatment	0.071	1	0.169
Position	0.133	1	0.063

Table S10: Model selection and summary statistics of ANOVA for effect of rotation on cumulative N_2O emissions (kg N_2O-N ha^{-1}) for both seasons. Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects. Results are presented in Fig 5c, S3c.

Models	AIC	BIC
mod1: cumN2O ~ treatment × position + (1 | block)	17.998	22.633
mod2: cumN2O ~ treatment + position (1 | block)	**17.946**	**21.809**

Random effects	Variance	SD
Block	0.011	0.105
Residual	0.087	0.295

Fixed effects	$\chi2$	df	P-value
Treatment	0.141	1	0.227
Position	0.260	1	0.109

$$Y_{ijk} = \beta_0 + \beta_1 \cdot \text{treatment}_{ij} + u_j + \epsilon_{ij}$$

Table S11: Model selection and summary statistics of ANOVA for effect of tillage (conventional, CA, CA+biochar) on cumulative N_2O emissions (kg N_2O-N ha^{-1}) in season 1 and 2. Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects. Results are presented in Fig 6a, Fig 6b, S4.

Models	AIC	BIC
mod1: cumN2O ~ treatment × season × position + (1 | block)	-37.262	-11.065
mod2: cumN2O ~ treatment × position (1 | block)	**-42.002**	**-27.001**

Random effects	Variance	SD
Block	0.000	0.000
Residual	0.017	0.132

Fixed effects	$\chi2$	df	P-value
Treatment	0.287	2	0.001
Position	0.028	1	0.213
Treatment × Position	0.197	2	0.006

$Y_{ijk} = \beta_0 + \beta_1 \cdot \text{treatment}_j + \beta_2 \cdot \text{position}_j + u_k + \epsilon_{ij}$

Table S12: Model selection and summary statistics of ANOVA for effect of tillage (conventional, CA, CA+biochar) on cumulative N_2O emissions (kg N_2O-N ha^{-1}) across all seasons. Variance and standard deviation (SD) are shown for the random effect and chi-square (χ^2), degrees of freedom (df) and significance (P-value) are shown for the fixed effects. Results are presented in Fig 6c, S4c.

Models	AIC	BIC
mod1: cumN2O ~ treatment × position + (1 | block)	**7.706**	**17.130**
mod2: cumN2O ~ treatment + position (1 | block)	11.709	18.777

Random effects	Variance	SD
Block	0.000	0.000
Residual	0.041	0.204

Fixed effects	$\chi2$	df	P-value
Treatment	0.583	2	0.003
Position	0.056	1	0.256
Treatment × Position	0.393	2	0.018

Results

Table S21: Soil and biochar properties. This is based on the background soil sampling (0-20 cm) taken in March 2023 for site characterisation.

Parameters	Gulu	Biochar
pH	6.71	9.74
TOC (%)	1.52	50.90
N (%)	0.11	0.76
C/N	13.82	67.30
Available P (mg kg^{-1})	6	710
Ca (mg kg^{-1})	620	10133
Fe (mg kg^{-1})	56	217
K (mg kg^{-1})	210	13000
Mg (mg kg^{-1})	120	1500
Zn (mg kg^{-1})	1.1	8.53
Clay %	4	
Silt %	16	
Sand %	80	
Texture	loamy sand	

Namatsheve et al. (2025)

Chamber positions

Fig S1: Fig chamber position between rows and in a basin, during the first season with pigeon pea on 11 May 2023.

Fig S2: Chamber position between rows and in a basin, during the first season with pigeon pea on 14 July 2023.

Results

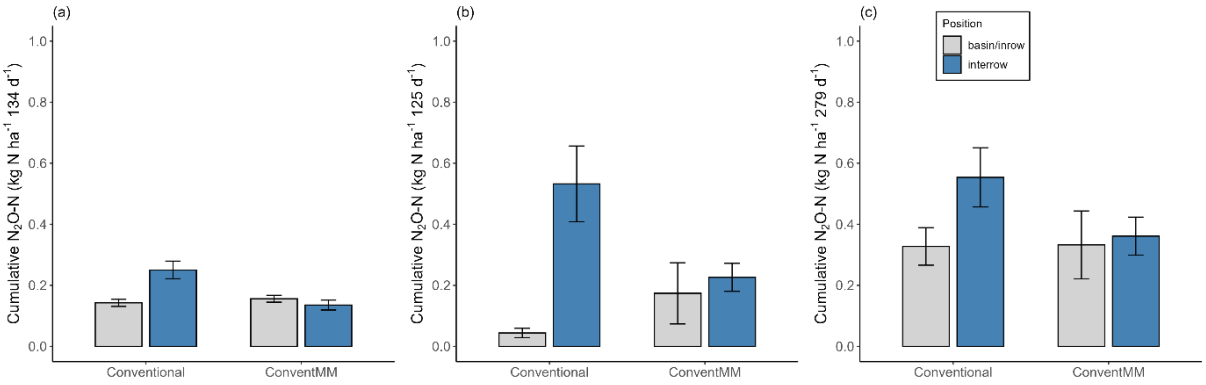

Fig S3: Effect of rotation on upscaled cumulative N_2O emissions, in Gulu. Assumption (0.12 basin and 0.88 interrow) for CA treatments and (0.50 basin and 0.50 interrow) for conventional.

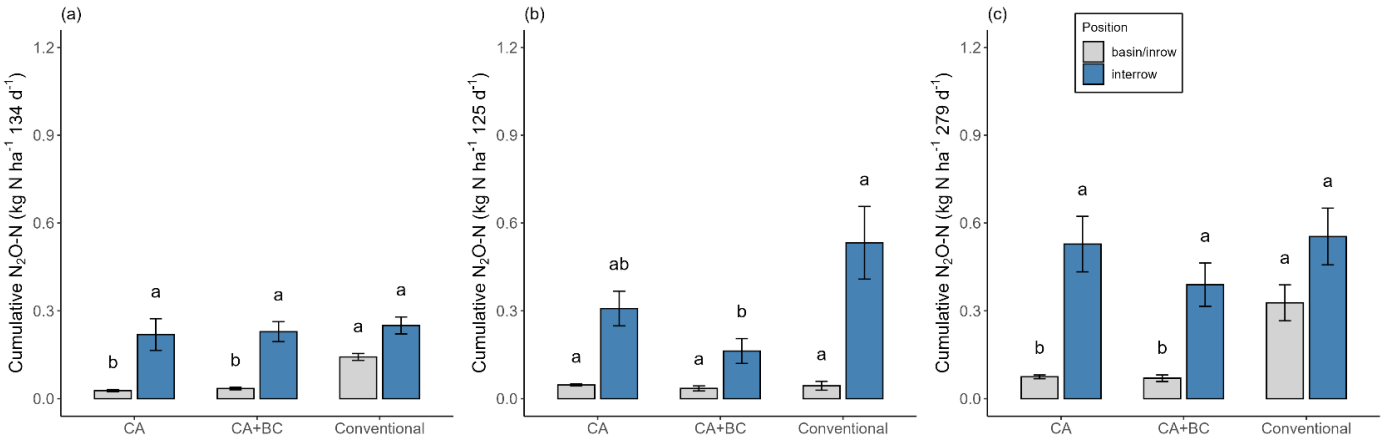

Fig S4: Effect of tillage on upscaled cumulative N_2O emissions, in Gulu. Assumption (0.12 basin and 0.88 interrow) for CA treatments and (0.50 basin and 0.50 interrow) for conventional.