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Impact of drying-rewetting cycles on nitrate removal rates in woodchip bioreactors

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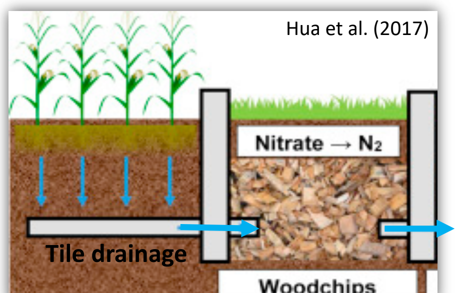
What are woodchip bioreactors?

- Agricultural BMP
- Intercept tile drainage
- Targets nitrate removal
- ~20 year lifespan
- NRCS approved
- 2-22 g N m^{-3} d^{-1} in field
- Mainly seen in Midwest



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What are drying-rewetting cycles?

- Cycle between dry/wet conditions
- Gradient of conditions

Dry | Unsaturated | Wet | Saturated

- Based on literature:
  - Stimulates respiration
  - Increases mineralization of C & N
  - Changes in microbial community

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Experimental Hypothesis

Do drying-rewetting cycles in woodchip bioreactors significantly improve treatment performance by increasing nitrate removal rates?

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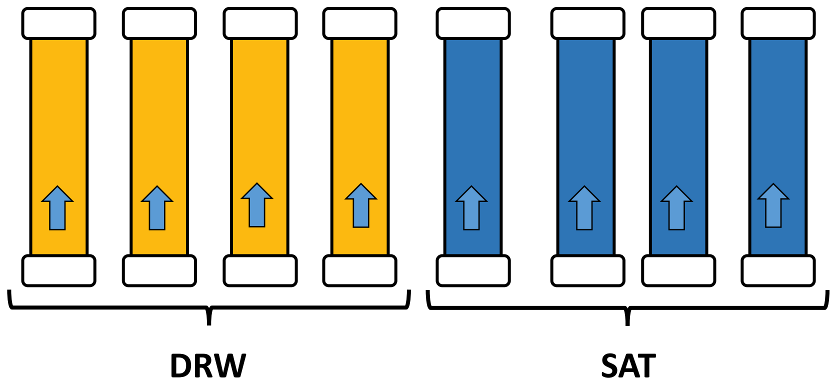
Methods

- Lab experiment with 8 woodchip-filled columns
- Continuous upflow (~8 hr HRT) for 10 months
- Two treatment groups
  - DRW – Drained once a week, unsaturated for 8 hr
  - SAT – Continuously saturated



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Methods

- Columns received ~20 mg NO3-N/L from stock tank
- Temperature and dissolved oxygen (DO) measured
- Lab samples analyzed by BAE Environmental Analysis Lab.
- Flow measured 2-3 times daily using graduated cylinders
- Microbial community composition analysis after 4 DRW cycles

High frequency water chemistry measurements

- Multi-point sampler coupled with spectrophotometer to measure column outflow (Birgand et al., 2016; Maxwell et al., 2018)
- Measurements for NO3 and dissolved organic carbon (DOC)
- Measurements were made every 2 hr. on each column and stock tank for 165 of 304 days

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Statistical Methods

- Compared volumetric removal rates (g N/m3/d) to normalize by flow
- Separated data into weekly periods, based on weekly DRW events
- SAS proc mixed to test significance of treatment effect in a mixed linear model
    - Repeated measures, account for autocorrelation
- Developed local calibration for spectrophotometer using partial least-squared regression (PLSR) methods

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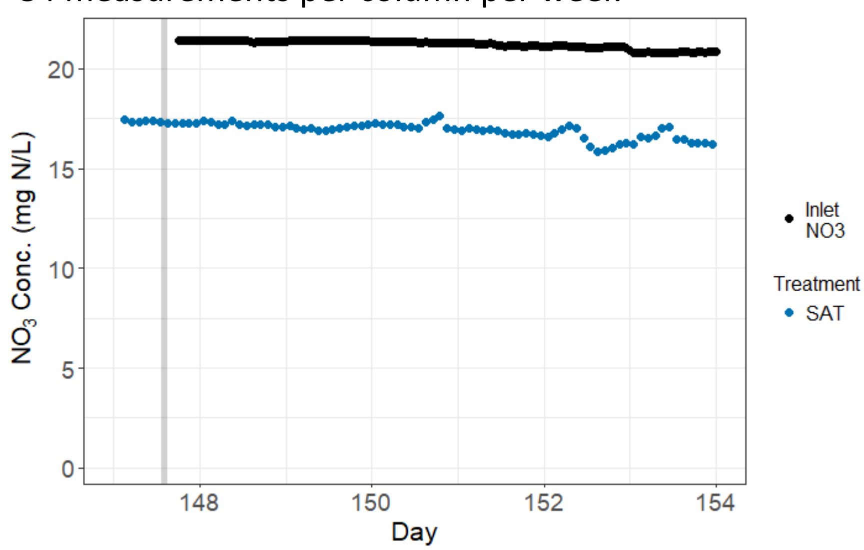
Results : High frequency data

84 measurements per column per week



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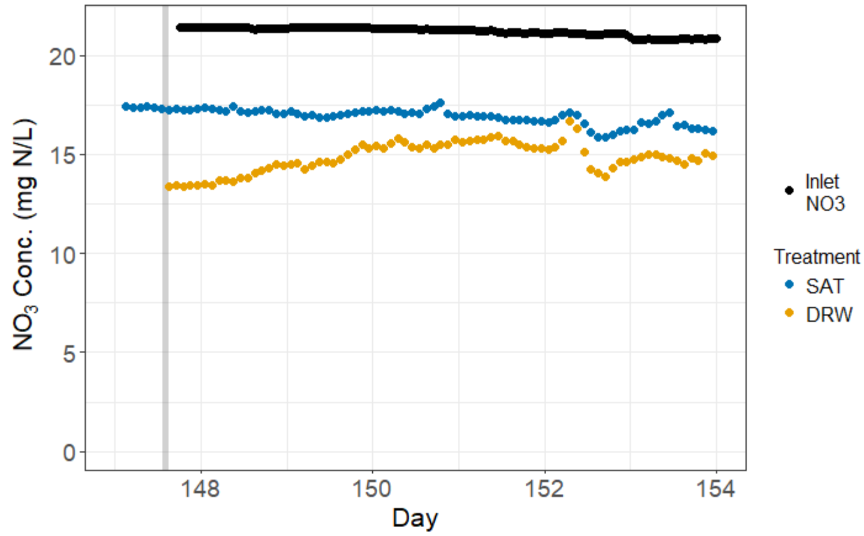
Results : High frequency data

84 measurements per column per week



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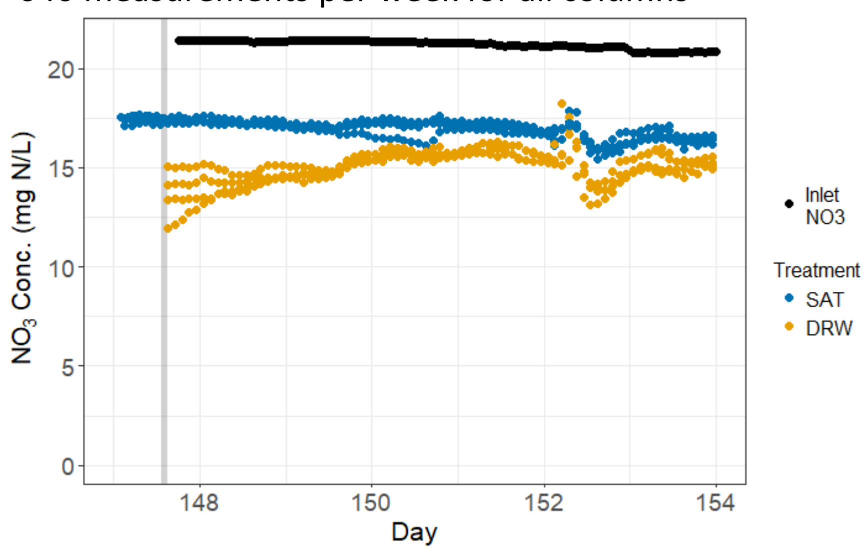
Results : High frequency data

640 measurements per week for all columns



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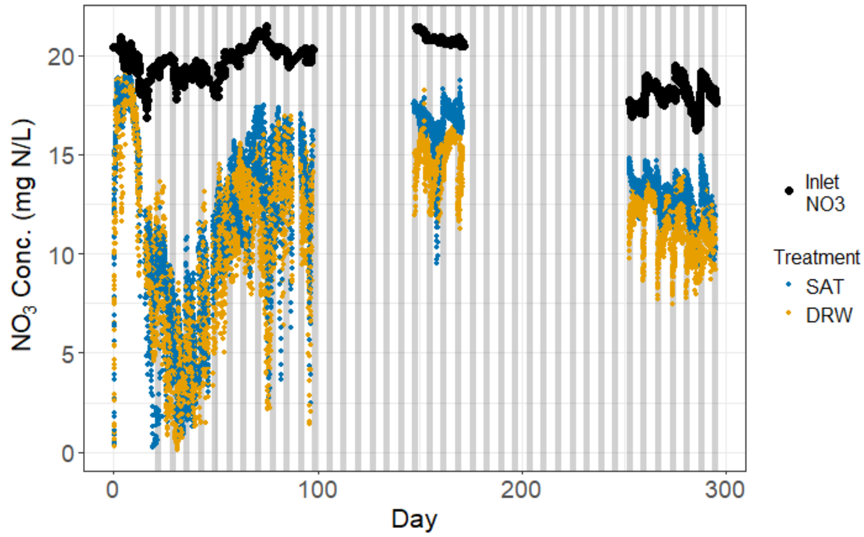
Results : High frequency data

10,000 measurements over 300 days for all columns



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Results : Mean volumetric removal rates for treatment groups, by period

	DRW Volumetric Rate (g N/m³/d)	SAT Volumetric Rate (g N/m³/d)	Difference in Means (s.d.)	Days
Period 0a	5.62	5.02	0.60 (0.28)	0 - 7
Period 0b	5.14	5.22	-0.082 (0.17)	7 - 14
Period 0c	14.50	14.99	-0.49 (0.34)	14 - 21
Period 1	20.54	20.82	-0.28 (0.34)	21 - 28
Period 2	25.38	23.79	1.59 (0.37)	28 - 35
Period 3	24.91	21.49	3.42 (0.25)	35 - 42
Period 4	23.80	18.77	5.03 (0.40)	42 - 49
Period 5	16.96	14.14	2.82 (0.23)	49 - 56
Period 6	15.18	12.94	2.24 (0.19)	56 - 63
Period 7	16.57	13.16	3.41 (0.26)	63 - 70
Period 8	22.02	16.09	5.93 (0.45)	70 - 77
Period 9	17.01	12.60	4.41 (0.37)	77 - 84
Period 10	13.07	9.71	3.36 (0.36)	84 - 91
Period 11	18.13	13.38	4.75 (0.36)	91 - 98
Period 19	11.96	8.35	3.60 (0.11)	147 - 154
Period 20	12.07	8.42	3.64 (0.11)	154 - 161
Period 21	10.92	7.63	3.29 (0.11)	161 - 168
Period 22**	14.22	7.88	6.34 (0.20)	168 - 171
Period 35	11.43	8.05	3.38 (0.13)	252 - 259
Period 36	12.04	8.91	3.13 (0.12)	259 - 266
Period 37	13.24	9.54	3.70 (0.13)	266 - 273
Period 38	12.67	9.30	3.37 (0.12)	273 - 280
Period 39	12.06	8.82	3.24 (0.13)	280 - 287

After the second weekly DRW event, removal rates in DRW columns were significantly greater in all periods.

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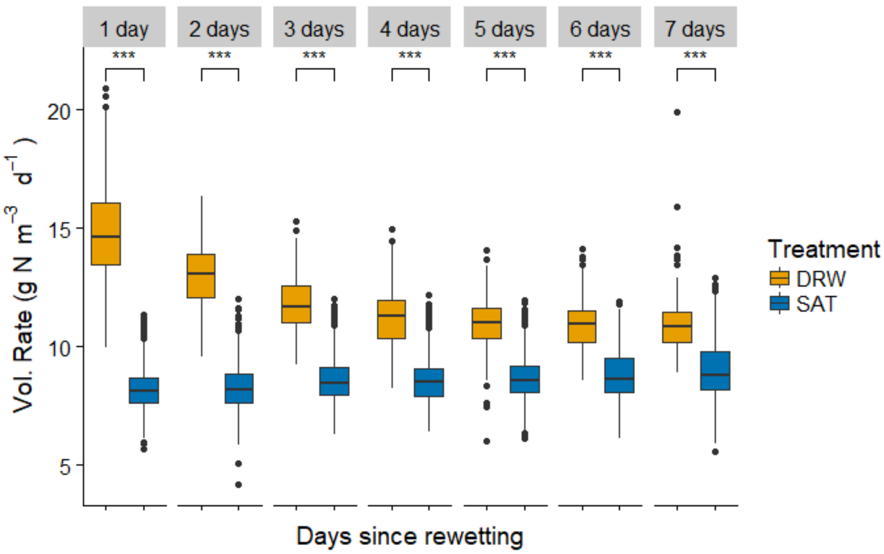
Nitrate response to DRW cycles



Removal rates in DRW columns decreased quickly within 3 days of rewetting, but were still significantly higher 7 days later

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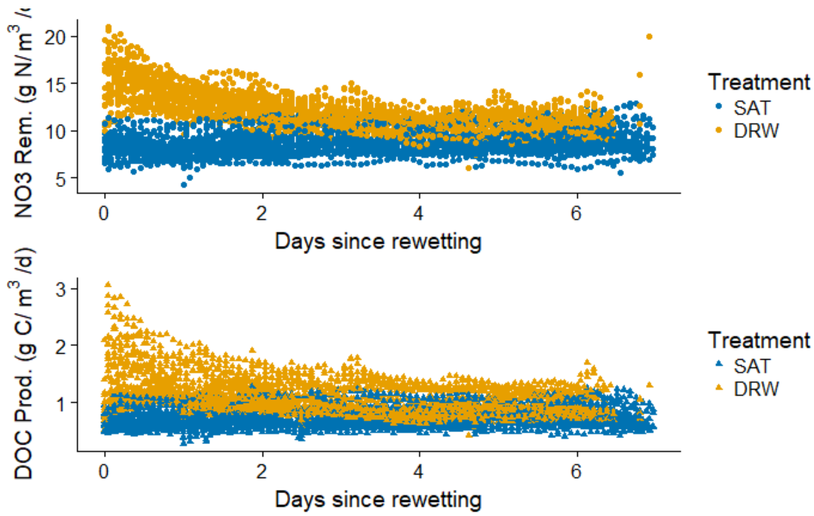
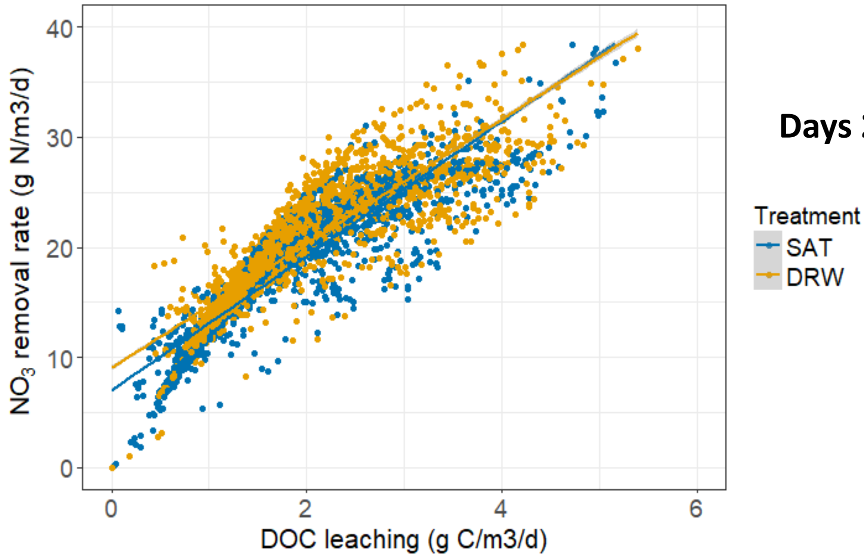
Does DOC production explain NO3 removal?



DOC production (leaching) rates decreased with nitrate removal after rewetting.

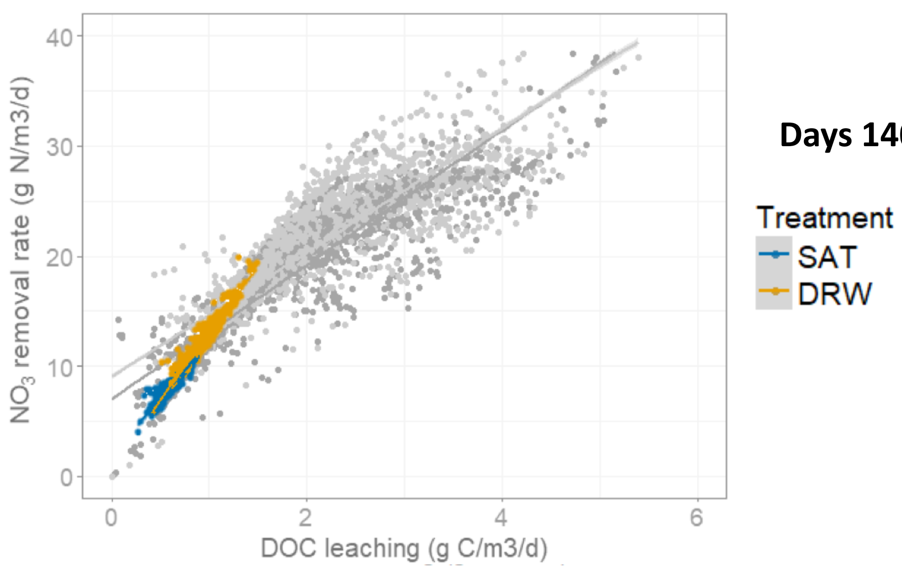
Does DOC production explain NO3 removal?



Days 20 - 100

DOC production (leaching) rates explained most of variance in removal (R^2 : 0.90 – 0.97)

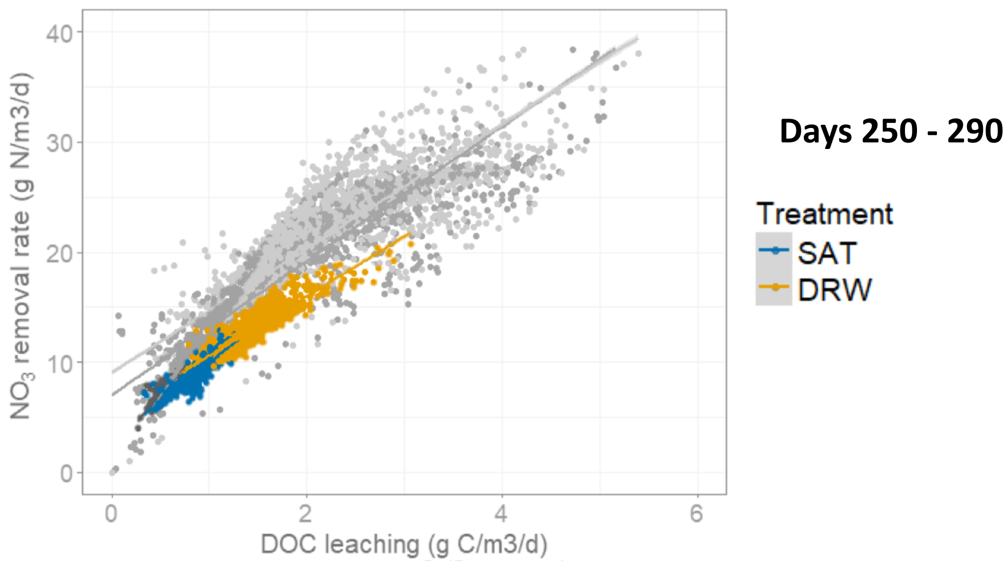
Does DOC production explain NO3 removal?



Days 140 - 180

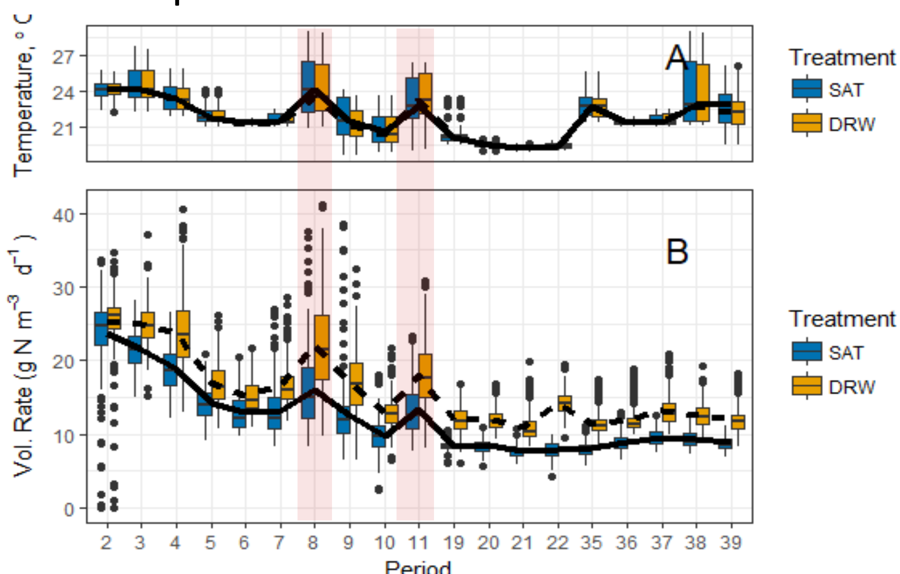
DOC production (leaching) rates explained most of variance in removal (R^2 : 0.90 – 0.97)

Does DOC production explain NO3 removal?



DOC production (leaching) rates explained most of variance in removal (R^2 : 0.90 – 0.97)

Does temperature affect treatment effect?



Difference in group removal rates were fairly consistent over the experiment, and appears to be an interaction effect with temperature

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Results : ANOVA Analysis

- Model best fitted by AR(1) covariance structure
- Treatment effect **is significant** : 3.36 g N/m3/d
- Estimate of treatment is roughly equal to difference in group means over the experiment

Covariance Parameter Estimates

Cov Parm	Subject	Estimate
AR(1)	Column	0.9745
Residual		31.7550

Fit Statistics

-2 Res Log Likelihood	32767.0
AIC (smaller is better)	32771.0
AICC (smaller is better)	32771.0
BIC (smaller is better)	32771.1

Solution for Fixed Effects

Effect	Treatment	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept		16.0269	0.7017	6	22.84	<.0001
Treatment	0	-3.3614	0.9687	6	-3.47	0.0133
Treatment	1	0	.	.	.	.

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	1	6	12.04	0.0133

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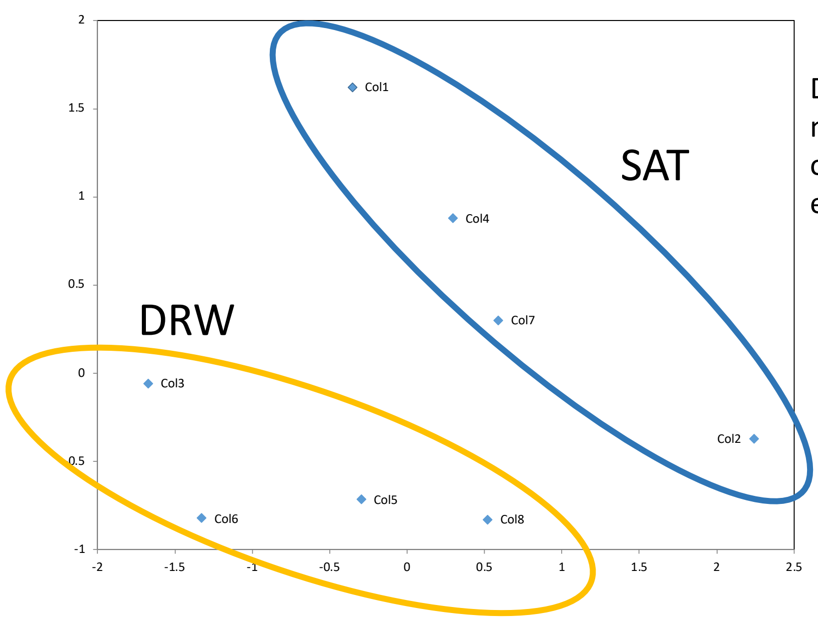
Results : Microbial analysis



Distinct differences in microbial communities after only 4 drying/rewetting events

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Experiment Conclusions

- Drying-rewetting cycles increased nitrate removal rates in woodchip bioreactors by 30-80%
- Aerobically-produced DOC is the most likely cause
- Increased removal even after 39 DRW cycles
- Most dramatic increases within 1-3 days of rewetting
- Microbial community shift

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Broader Conclusions

- Bioreactor performance can be improved through design/management
- Implications for management of other carbon-substrate BMPs (i.e. wetlands)
- DOC availability and microbial community results could explain high productivity of other dry/wet landscapes (i.e. riparian zones, saturated buffers)

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STROUD WATER RESEARCH CENTER ➤ Microbial Analysis

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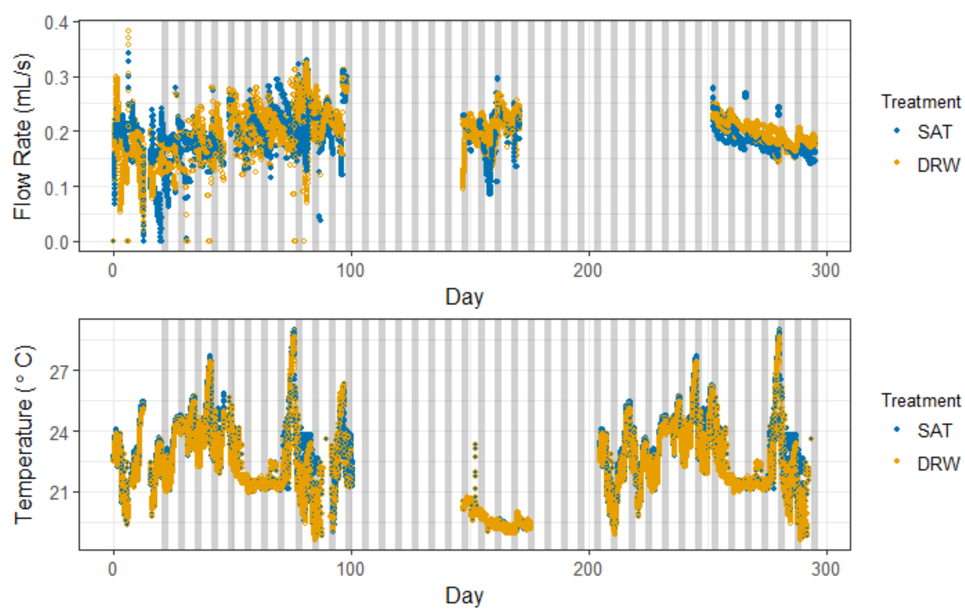
Results : Flow and temperature



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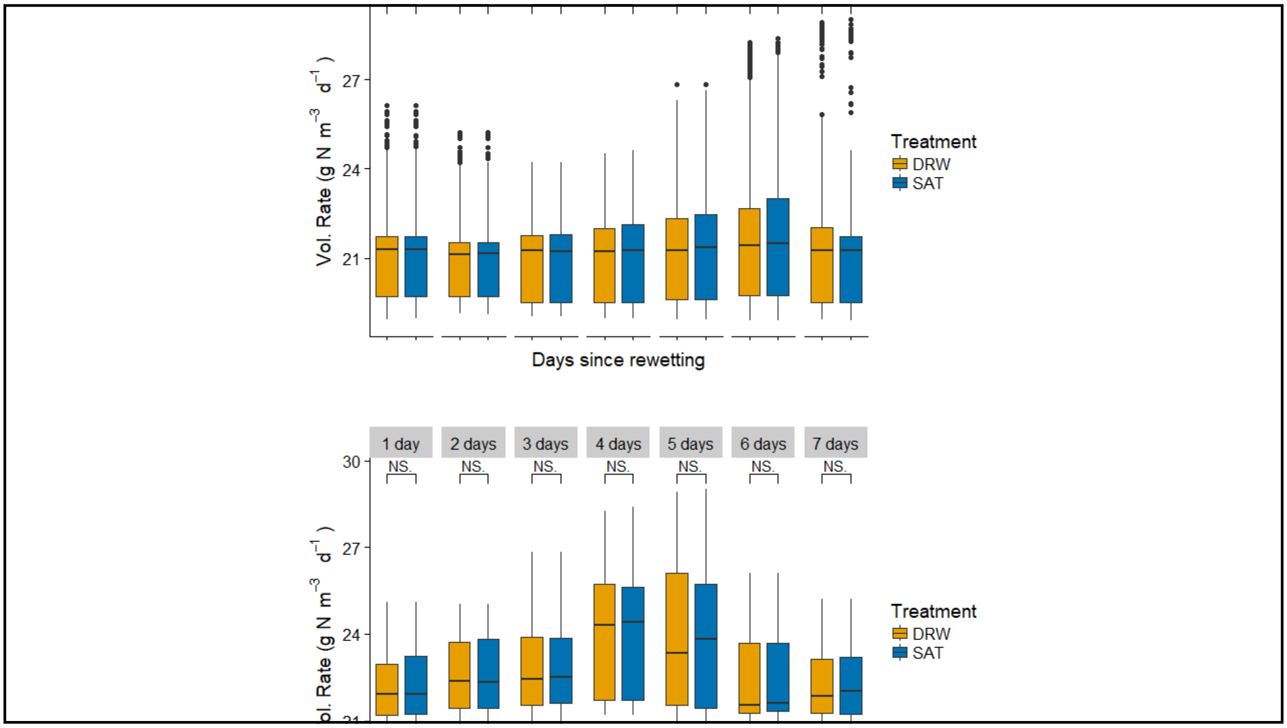
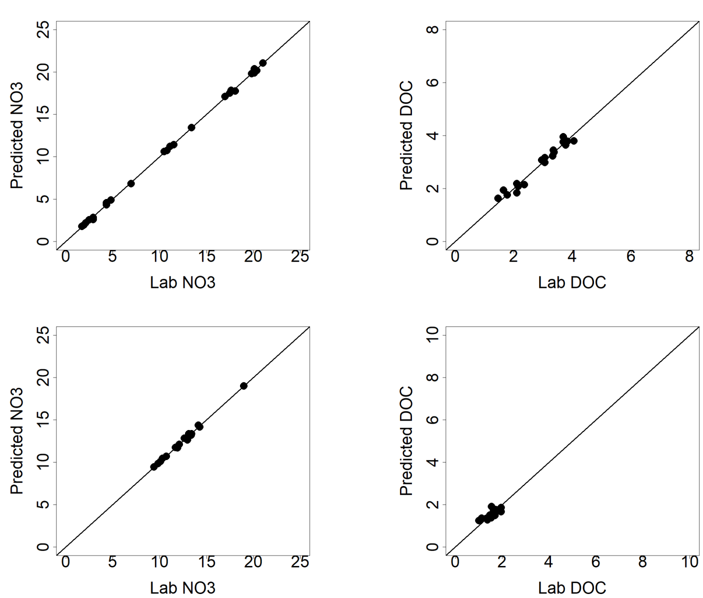


Results : Calibration of spectrophotometer



NO3

$R2 > 0.99$

RMSEP < 0.30 mg/L

DOC

R2 : 0.56 – 0.96

RMSEP < 0.25 mg/L

Good fit, reliable data!