

**Runoff Nutrient Losses from Tall Fescue Pastures Varying in Endophyte Association,
Fertilization, and Harvest Management**

Authors

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Rainfall variability and influence on runoff and nutrient load

A prominent feature of the weather pattern during the study was one of sustained drought and wet periods. Several approaches can be used to elucidate this contrast: patterns of deviations of the 12 months running average rainfall from the long-term annual average (figure 2 in the main text copied below; e.g. Endale et al. 2011), Standard Precipitation Index (e.g. Endale et al. 2011); and comparison of monthly rainfall to the long-term monthly average rainfall, etc.

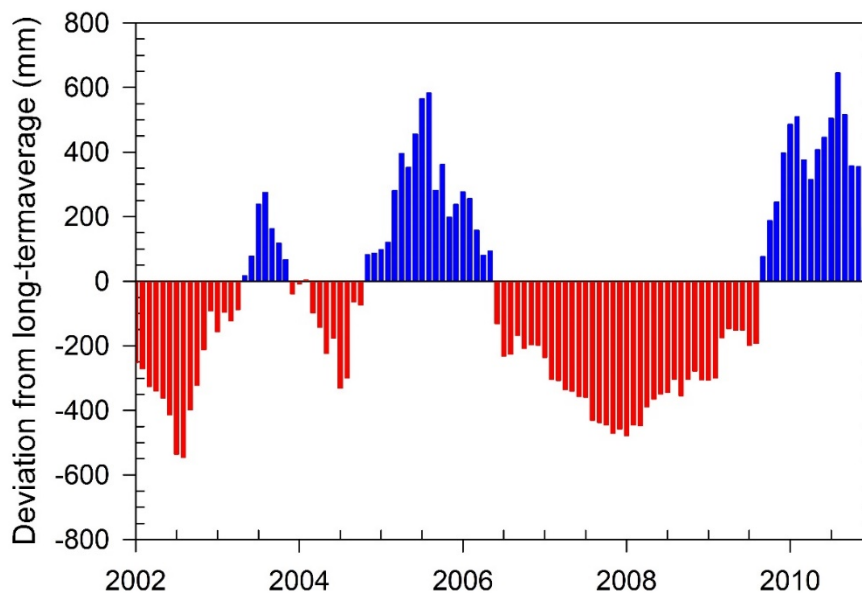


Figure 2. Deviation of the 12 months running average rainfall during the study from the 74 year (1937-2010) annual average of 1240 mm near Watkinsville, Georgia (Copied here from main text).

Figure 2 shows extended periods where the deviation of the 12 months running average rainfall was below and above the 74-year annual average. Mean negative deviations were: -283 mm (16 consecutive months, January 2002 through April 2003); -132 mm (11 consecutive months, December 2003 through October 2004); and -303 mm (39 consecutive months, June 2006 through August 2009). Mean positive deviations were: +136 mm (7 consecutive months, May 2003 through November 2003); +261 mm (19 consecutive months, November 2004 through May 2006); and +374 mm (16 consecutive

months, September 2009 through December 2010). The driest and 7th driest years in 74-year of record occurred in 2007 (787 mm) and 2008 (884 mm), respectively. Some very wet months occurred in 2003, 2004, 2005, and 2009 (1691 mm; 3rd wettest year in 74 years).

Under these conditions, 77 runoff events were recorded with runoff from one or more paddocks during the study (April 2002 through April 2010). In 92% of these cases, runoff occurred when event rainfall was ≥ 20 mm. The number of runoff events were similar during these contrasting periods (36 and 37; the balance 4 runoff events from the total of 77 occurred in January and February 2010). During the negative deviation months, the average runoff causing rainfall was 45.2 mm (± 3.9 ; range 10.4 to 108.2) and average duration was 19.7 h (± 2.1 ; range 2.0 to 54.9). Equivalent values during the positive deviation months were: 49.8 mm (± 4.0 ; range 13.0 to 114.4) and 15.3 h (± 1.9 ; range 0.8 to 48.4), respectively. Total runoff across paddocks during the 30 months of positive deviation was 2.1 times (4631 mm) that from the 66 months of negative deviation (2127 mm). During the positive deviation period, the mean rainfall partitioned into runoff was 14.3% (range 0.4% to 52.9%) in contrast to 8.0% (range 0.1% to 33.0%) during the negative deviation period.

Monthly rainfall during individual months of either deviation period could be below, equal to, or above the long-term monthly average rainfall with a consequence on runoff generation and nutrient loss. We divided the months according to this criteria and evaluated the rainfall, runoff, and total nutrient distribution accordingly. When monthly rainfall was 20 mm or greater below the 74- year average monthly rainfall, we assigned a 'below average' designation. When monthly rainfall was equal to the 74-year average monthly rainfall ± 20 mm, we assigned an 'average' designations. And when monthly rainfall was 20 mm or greater above the 74-year average monthly rainfall, we assigned an 'above average' designation. The choice of 20 mm was subjective but represents approximately one

fifth of the average monthly rainfall during the study period. [Supplemental tables S1 to S5](#) (below) give details of rainfall, runoff, and total nutrient load distributions during these and overall period.

From May 2002 (first month of runoff data) through December 2009, monthly rainfall was below average in 52.2% (48 months), average in 20.7% (19 months), and above average in 27.2% (25 months) of the time ([supplemental table S1](#)). Monthly mean rainfall during the above average and average monthly periods was 3.1 and 1.6 times that during the below average period (183.5, 96.5, and 60.1 mm, respectively). Mean runoff total across all paddocks during the above average and average monthly periods was 15.2 and 1.9 times that during the below average period (15.99, 2.02, and 1.06 mm ha⁻¹, respectively). The mean rainfall partitioned into runoff across all paddocks during the above average and average monthly periods was 6.4 and 1.7 times that during the below average period (7.1%, 1.9%, and 1.1%, respectively). [Supplemental table S1](#) gives the breakdowns by forage harvest and fertilizer treatments across fescue-endophyte associations.

[Supplemental table S2](#) gives breakdown of total annual nutrient loads for the original (untransformed) data, expressed in kg ha⁻¹, by periods of rainfall variability and by forage and fertilizer treatments. To try and give a complete picture for total annual load, we had to estimate runoff volume and nutrient loads for some events where, due to problems with in-field sampling infrastructure or issues during laboratory analysis, data were not available. Missing event values in any one year were assigned the average value obtained from the 10th to 85th percentile available data for that year, except where the value for the 85th percentile was =>3-fold greater than that of the 80th percentile, in which case the average of the 10th to 80th percentile data were used.

Across all paddocks, the monthly mean nutrient load for the above monthly average rainfall period was 9- to 28-fold greater than that for the below average period (0.27 to 7.24 kg ha⁻¹ vs. < 0.4 kg ha⁻¹). Similarly, total monthly load from the above monthly average rainfall period was 3- to 15-fold greater

than that from the below average period (6 to 88 kg ha⁻¹ vs. < 12 kg ha⁻¹). Loads were also greater from the above average monthly rainfall period compared with the average period: 1.6- to 33.0-fold for monthly mean and 2- to 44-fold for monthly total for all nutrients except nitrate-N for which loads were lower (0.35- and 0.47-fold, respectively). Refer to [supplemental table S2](#) for additional details.

[Supplementary tables S3](#) gives summary statistics for nutrient concentrations and loads based on untransformed data, parsed into periods with and without cattle as well as all periods. Mean nitrate-N concentrations (mg L⁻¹) across the six grazed treatments varied from 0.08 to 0.26 without cattle (n = 41 to 69) and from 0.29 to 1.03 with cattle (n = 31 to 52), respectively. For ammonium-N, equivalent values were 0.20 to 0.84 and 0.41 to 0.85. For ortho-P, equivalent values were 0.72 to 2.57 and 1.32 to 3.90, respectively. Mean concentrations for TN varied from 2.48 to 3.34 without cattle (n = 22 to 36) and from 2.41 to 6.06 with cattle (n = 4 to 9), respectively. Equivalent values for TP were 1.13 to 3.06 and 1.42 to 4.77, respectively. Numerically, therefore, mean concentrations with cattle were 1.3 to 7.3 times greater than those without cattle for nitrate-N, 1.5 to 2.3 times greater for ortho-P, 1.1 to 1.9 times greater for TP, and up to 1.8 times greater for TN. For ammonium-N, concentration was numerically greater from period with cattle in grazed wild fescue under broiler litter (1.2-fold) and grazed free fescue with inorganic fertilizer (4.2-fold) only. For the remaining grazed treatments, concentration was up to 1.6-fold greater from periods without than with cattle. For the hayed treatment, overall mean concentration was close to 0.5 mg L⁻¹ for all nutrients but TN (2.9 mg L⁻¹). Refer to [supplementary table S3](#) for additional details.

Mean nitrate-N load (kg ha⁻¹) across the six grazed treatments varied from 0.003 to 0.042 without cattle and from 0.007 to 0.103 with cattle, respectively. For ammonium-N, equivalent values were 0.013 to 0.061 and 0.011 to 0.051. For ortho-P, equivalent values were 0.059 to 0.181 and 0.130 to 0.470, respectively. Mean load for TN varied from 0.227 to 0.422 without cattle and from 0.024 to

0.052 with cattle. Equivalent values for TP were 0.143 to 0.260 and 0.012 to 0.050, respectively. Numerically, therefore, mean load with cattle were 1.3 to 7.5 times greater than those without cattle for nitrate-N, and 1.5 to 2.8 times greater for ortho-P. Mean ammonium-N load was 2.1 to 4.0 times greater with than without cattle in grazed inorganically fertilized fescue treatments. For grazed organically fertilized fescue the ratio was ~0.37. Similarly the ratio for mean TN and TP load was 0.6 to 0.24. For the hayed treatment, overall mean load was $< 0.3 \text{ kg ha}^{-1}$ for all nutrients. Refer to [supplementary table S3](#) for additional details.

Summary statistics based on total annual nutrient load (kg ha^{-1}) with breakdown by treatment are shown in [supplemental table S4](#). Mean total annual nutrient load (kg ha^{-1}) for all grazed organic and inorganic fertilizer treatments was 3.2 and 11.2, respectively, for nitrate-N; 10.6 and 7.6, respectively, for ammonium-N; 69.8 and 35.8, respectively, for ortho-P; 23.6 and 33.9, respectively, for TN; and 19.8 and 15.3, respectively, for TP. In the hayed treatment, values in order of above listed nutrients were, respectively, 7.9, 5.3, 3.6, 10.3, and 1.92. Recall that samples for TN and TP came only from 2007 and later. Refer to [supplemental table S4](#) for further details about variation among fescues within each fertilization treatment.

Finally, [supplemental table S5](#) gives total annual nutrient loads. Total annual nitrate-N load was $< 1.0 \text{ kg ha}^{-1}$ in all treatments and all years except for 2002 when total load was $\sim 6.6 \text{ kg ha}^{-1}$ for grazed and hayed treatments under inorganic fertilization, and in 2009 when grazed inorganic treatment had load of 2.9 kg ha^{-1} . Total annual ammonium load also was $< 1.0 \text{ kg ha}^{-1}$ with exception of 2002 (inorganic, hayed & grazed), 2005 (grazed, organic), and 2009 (inorganic, grazed & hayed) when loads varied from 1.49 to 7.3 kg ha^{-1} . Total annual ortho-P load varied from 1.0 to 25.1 kg ha^{-1} except in 2008 when it was $< 0.2 \text{ kg ha}^{-1}$. Annual loads for TN and TP (data 2007-2009 only) were orders of magnitude greater in 2009 compared with loads in 2007 and 2008. Total estimated loads (kg ha^{-1}) for

the 8 years across all treatments were 22.2 for nitrate-N, 23.5 for ammonium-N, and 109.3 for ortho-P. Total loads from 2007 to 2009 for TN and TP were 67.7 and 37.0 kg ha⁻¹, respectively.

Supplemental table S1.

Summary statistics for total monthly rainfall and runoff by treatment from April 2002 through December 2009 divided into periods where monthly rainfall was below, equal to, or above the long-term (74 years) average monthly rainfall. *

Variable	Harvest/Fertilizer	Mean	SE	Median	Minimum	Maximum	Total
Below average monthly rainfall (n = 48)							
Monthly rainfall - mm	All	60.1	3.5	64.1	0.8	116.1	2887.0
Monthly rainfall deviation - mm	All	-45.9	3.0	-44.2	-111.1	-19.6	-2204.1
Monthly total runoff – mm/ha	Grazed Organic	0.92	0.47	0.00	0.00	18.29	44.24
	Grazed Inorganic	1.14	0.62	0.00	0.00	25.86	54.82
	Hayed	1.19	0.56	0.00	0.00	18.88	56.96
	All	1.06	0.55	0.00	0.00	21.57	50.64
Monthly percent runoff	Grazed Organic	0.96	0.49	0.00	0.00	20.11	NA
	Grazed Inorganic	1.20	0.65	0.00	0.00	28.44	NA
	Hayed	1.25	0.56	0.00	0.00	20.76	NA
	All	1.11	0.57	0.00	0.00	23.72	NA
Average monthly rainfall (n = 19)							
Monthly rainfall - mm	All	96.5	3.6	96.8	73.9	131.8	1832.6
Monthly rainfall deviation - mm	All	0.2	2.5	-0.2	-18.1	15.7	3.6
Monthly total runoff – mm/ha	Grazed Organic	1.81	0.89	0.22	0.00	13.53	34.39
	Grazed Inorganic	2.07	1.02	0.19	0.00	15.53	39.33
	Hayed	2.48	0.99	1.07	0.00	16.43	47.19
	All	2.02	0.96	0.34	0.00	14.82	38.43
Monthly percent runoff	Grazed Organic	1.69	0.81	0.24	0.00	12.96	NA
	Grazed Inorganic	1.94	0.94	0.20	0.00	14.88	NA
	Hayed	2.41	0.92	1.22	0.00	15.74	NA
	All	1.90	0.88	0.33	0.00	14.19	NA
Above average monthly rainfall (n = 25)							
Monthly rainfall - mm	All	183.5	12.5	159.3	109.2	325.9	4588.3
Monthly rainfall deviation - mm	All	82.0	12.6	57.8	21.4	235.9	2049.4
Monthly total runoff – mm/ha	Grazed Organic	13.35	3.05	6.06	0.00	48.08	333.74
	Grazed Inorganic	18.33	4.19	8.45	0.00	64.11	458.26
	Hayed	16.88	3.62	8.63	0.00	52.92	421.90
	All	15.99	3.61	7.68	0.00	53.89	399.69
Monthly percent runoff	Grazed Organic	5.93	1.15	3.13	0.00	19.14	NA
	Grazed Inorganic	8.18	1.60	4.73	0.00	27.80	NA
	Hayed	7.66	1.35	6.33	0.00	22.94	NA
	All	7.14	1.36	3.99	0.00	23.37	NA

* Criteria for below to above average monthly rainfall categories are explained in the text. NA not applicable.

Supplemental table S2

Summary statistics for total monthly nutrient loads (kg ha⁻¹) by treatment from April 2002 through December 2009 divided into periods where monthly rainfall was below, equal to, or above average compared with the long-term (74 years) average monthly rainfall. *

Nutrient	Harvest/Fertilizer	Mean	SE	Median	Minimum	Maximum	Total
Below average monthly rainfall (n = 48)							
Nitrate-N	Grazed Organic	0.010	0.007	0.000	0.000	0.338	0.464
	Grazed Inorganic	0.008	0.004	0.000	0.000	0.155	0.371
	Hayed	0.002	0.001	0.000	0.000	0.036	0.104
	All	0.020	0.011	0.000	0.000	0.529	0.940
Ammonium-N	Grazed Organic	0.008	0.003	0.000	0.000	0.119	0.386
	Grazed Inorganic	0.012	0.006	0.000	0.000	0.223	0.574
	Hayed	0.002	0.001	0.000	0.000	0.023	0.088
	All	0.022	0.009	0.000	0.000	0.267	1.048
Ortho-P	Grazed Organic	0.153	0.094	0.000	0.000	4.352	7.331
	Grazed Inorganic	0.084	0.057	0.000	0.000	2.705	4.026
	Hayed	0.004	0.003	0.000	0.000	0.129	0.203
	All	0.241	0.153	0.000	0.000	7.186	11.559
Total N	Grazed Organic	0.150	0.095	0.000	0.000	2.033	3.294
	Grazed Inorganic	0.185	0.137	0.000	0.000	3.002	4.060
	Hayed	0.052	0.043	0.000	0.000	0.946	1.154
	All	0.387	0.274	0.000	0.000	5.981	8.509
Total P	Grazed Organic	0.215	0.161	0.000	0.000	3.529	4.728
	Grazed Inorganic	0.151	0.120	0.000	0.000	2.634	3.316
	Hayed	0.007	0.005	0.000	0.000	0.118	0.154
	All	0.373	0.286	0.000	0.000	6.282	8.198
Average monthly rainfall (n = 19)							
Nitrate-N	Grazed Organic	0.053	0.041	0.007	0.000	0.781	0.999
	Grazed Inorganic	0.349	0.337	0.005	0.000	6.420	6.632
	Hayed	0.362	0.353	0.003	0.000	6.711	6.872
	All	0.763	0.731	0.025	0.000	13.912	14.503
Ammonium-N	Grazed Organic	0.059	0.038	0.015	0.000	0.721	1.123
	Grazed Inorganic	0.189	0.165	0.016	0.000	3.162	3.595
	Hayed	0.125	0.119	0.004	0.000	2.273	2.374
	All	0.373	0.322	0.033	0.000	6.156	7.092
Ortho-P	Grazed Organic	0.351	0.179	0.085	0.000	3.391	6.660
	Grazed Inorganic	0.163	0.060	0.054	0.000	1.010	3.096

	Hayed	0.023	0.008	0.011	0.000	0.106	0.443
	All	0.537	0.240	0.168	0.000	4.508	10.199
Total N	Grazed Organic	0.136	0.120	0.011	0.000	0.732	0.817
	Grazed Inorganic	0.076	0.058	0.012	0.000	0.360	0.455
	Hayed	0.009	0.005	0.003	0.000	0.024	0.052
	All	0.221	0.177	0.034	0.000	1.097	1.324
Total P	Grazed Organic	0.082	0.067	0.008	0.000	0.414	0.492
	Grazed Inorganic	0.025	0.019	0.004	0.000	0.118	0.153
	Hayed	0.004	0.003	0.001	0.000	0.017	0.024
	All	0.111	0.089	0.014	0.000	0.548	0.668
Above average monthly rainfall (n = 25)							
Nitrate-N	Grazed Organic	0.069	0.023	0.020	0.000	0.460	1.716
	Grazed Inorganic	0.166	0.098	0.019	0.000	2.473	4.162
	Hayed	0.035	0.015	0.009	0.000	0.353	0.886
	All	0.271	0.127	0.048	0.000	3.103	6.764
Ammonium-N	Grazed Organic	0.362	0.260	0.085	0.000	6.578	9.056
	Grazed Inorganic	0.137	0.026	0.121	0.000	0.434	3.413
	Hayed	0.114	0.083	0.028	0.000	2.102	2.856
	All	0.613	0.277	0.254	0.000	6.818	15.325
Ortho-P	Grazed Organic	2.232	0.661	1.018	0.000	12.852	55.798
	Grazed Inorganic	1.142	0.345	0.418	0.000	6.529	28.557
	Hayed	0.120	0.036	0.054	0.000	0.700	2.990
	All	3.494	1.012	1.996	0.000	17.896	87.346
Total N	Grazed Organic	2.430	0.979	1.930	0.000	8.314	19.440
	Grazed Inorganic	3.677	1.466	2.704	0.000	12.237	29.414
	Hayed	1.131	0.463	0.707	0.000	3.873	9.051
	All	7.238	2.899	5.523	0.000	24.425	57.905
Total P	Grazed Organic	1.813	0.909	1.271	0.000	7.898	14.500
	Grazed Inorganic	1.477	0.789	0.932	0.000	6.772	11.812
	Hayed	0.218	0.120	0.104	0.000	1.024	1.744
	All	3.507	1.815	2.499	0.000	15.695	28.057

* Criteria for below to above average monthly rainfall categories are explained in the text.

Supplementary table S3

Descriptive statistics for untransformed nutrient concentration and load data for all periods and for periods with no cattle and those with cattle.

Treatment *			Concentration [†] mg L ⁻¹							Load [†] kg ha ⁻¹								
Forage	Fert.	Fescue	Mean	SE	Min	Max	Q1	Median	Q3	Mean	SE	Min	Max	Q1	Median	Q3	Sum	Obs.††
Nitrate-N All																		
Grazed	BL	Novel	0.20	0.03	0.00	1.76	0.00	0.07	0.24	0.011	0.004	0.000	0.409	0.000	0.002	0.006	1.336	119
	BL	Wild	0.29	0.06	0.00	3.66	0.04	0.09	0.23	0.006	0.001	0.000	0.047	0.000	0.001	0.006	0.532	96
	BL	Free	0.31	0.07	0.00	3.42	0.03	0.08	0.30	0.016	0.005	0.000	0.291	0.000	0.002	0.015	1.132	72
	IF	Novel	0.31	0.09	0.00	8.28	0.00	0.07	0.23	0.009	0.004	0.000	0.362	0.000	0.001	0.008	0.932	99
	IF	Wild	0.56	0.22	0.00	20.36	0.01	0.09	0.24	0.068	0.040	0.000	3.467	0.000	0.002	0.005	6.869	101
	IF	Free	0.39	0.08	0.00	5.47	0.03	0.09	0.22	0.026	0.012	0.000	1.251	0.001	0.004	0.009	2.990	117
Hayed	IF	Novel	0.48	0.20	0.00	22.97	0.00	0.06	0.15	0.058	0.045	0.000	5.658	0.000	0.001	0.007	7.413	127
Nitrate-N No Cattle																		
Grazed	BL	Novel	0.13	0.03	0.00	1.20	0.00	0.03	0.16	0.007	0.004	0.000	0.240	0.000	0.000	0.005	0.500	67
	BL	Wild	0.26	0.09	0.00	3.66	0.00	0.06	0.18	0.005	0.001	0.000	0.043	0.000	0.001	0.007	0.291	59
	BL	Free	0.15	0.04	0.00	1.13	0.01	0.05	0.15	0.012	0.006	0.000	0.222	0.000	0.002	0.006	0.486	41
	IF	Novel	0.08	0.02	0.00	0.53	0.00	0.03	0.10	0.003	0.001	0.000	0.025	0.000	0.001	0.002	0.151	57
	IF	Wild	0.22	0.10	0.00	5.23	0.00	0.03	0.12	0.042	0.037	0.000	2.130	0.000	0.001	0.003	2.442	58
	IF	Free	0.26	0.09	0.00	4.46	0.00	0.04	0.12	0.007	0.002	0.000	0.133	0.000	0.002	0.007	0.480	69
Hayed	IF	Novel	0.25	0.09	0.00	5.58	0.00	0.03	0.11	0.006	0.002	0.000	0.093	0.000	0.001	0.005	0.427	74
Nitrate-N With Cattle																		
Grazed	BL	Novel	0.29	0.05	0.00	1.76	0.07	0.13	0.32	0.016	0.008	0.000	0.409	0.001	0.003	0.012	0.836	52
	BL	Wild	0.34	0.07	0.00	1.90	0.07	0.17	0.52	0.007	0.002	0.000	0.047	0.000	0.002	0.006	0.242	37
	BL	Free	0.52	0.14	0.00	3.42	0.08	0.22	0.77	0.021	0.009	0.000	0.291	0.000	0.007	0.018	0.646	31
	IF	Novel	0.61	0.21	0.00	8.28	0.07	0.16	0.50	0.019	0.009	0.000	0.362	0.001	0.006	0.016	0.781	42
	IF	Wild	1.03	0.49	0.00	20.36	0.10	0.19	0.45	0.103	0.081	0.000	3.467	0.001	0.003	0.023	4.427	43
	IF	Free	0.59	0.16	0.00	5.47	0.08	0.15	0.52	0.052	0.029	0.000	1.251	0.003	0.005	0.022	2.510	48
Hayed	IF	Novel	0.81	0.46	0.00	22.97	0.06	0.10	0.20	0.132	0.107	0.000	5.658	0.001	0.002	0.008	6.985	53
Ammonium-N All																		
Grazed	BL	Novel	0.43	0.13	0.00	10.80	0.06	0.11	0.21	0.043	0.022	0.000	2.028	0.002	0.005	0.012	5.101	119
	BL	Wild	0.74	0.17	0.00	9.40	0.08	0.16	0.39	0.024	0.010	0.000	0.729	0.001	0.004	0.013	2.263	96
	BL	Free	0.76	0.22	0.00	11.23	0.09	0.16	0.39	0.042	0.017	0.000	0.999	0.002	0.008	0.027	3.048	72
	IF	Novel	0.55	0.20	0.00	15.54	0.07	0.17	0.27	0.018	0.006	0.000	0.565	0.001	0.005	0.016	1.751	99
	IF	Wild	0.69	0.27	0.00	24.21	0.05	0.10	0.24	0.029	0.013	0.000	1.265	0.001	0.005	0.021	2.919	101
	IF	Free	0.47	0.17	0.00	19.28	0.07	0.14	0.28	0.024	0.006	0.000	0.534	0.002	0.007	0.023	2.752	117
Hayed	IF	Novel	0.46	0.14	0.00	13.29	0.04	0.06	0.15	0.040	0.020	0.000	1.822	0.001	0.004	0.010	5.038	127
Ammonium-N No Cattle																		
Grazed	BL	Novel	0.43	0.20	0.00	10.80	0.05	0.08	0.16	0.061	0.038	0.000	2.028	0.001	0.005	0.012	4.102	67
	BL	Wild	0.68	0.21	0.03	8.83	0.07	0.11	0.34	0.031	0.016	0.000	0.729	0.001	0.004	0.013	1.840	59
	BL	Free	0.84	0.38	0.03	11.23	0.08	0.11	0.22	0.056	0.030	0.000	0.999	0.002	0.007	0.015	2.296	41
	IF	Novel	0.65	0.35	0.03	15.54	0.07	0.13	0.21	0.012	0.003	0.000	0.107	0.002	0.004	0.016	0.679	57
	IF	Wild	0.78	0.45	0.00	24.21	0.05	0.07	0.12	0.013	0.003	0.000	0.147	0.001	0.004	0.015	0.741	58
	IF	Free	0.20	0.04	0.00	1.58	0.06	0.09	0.19	0.013	0.002	0.000	0.065	0.003	0.007	0.018	0.915	69
Hayed	IF	Novel	0.51	0.21	0.01	13.29	0.04	0.06	0.10	0.035	0.023	0.000	1.718	0.001	0.004	0.009	2.558	74
Ammonium With Cattle																		
Grazed	BL	Novel	0.43	0.13	0.00	6.20	0.08	0.15	0.39	0.019	0.008	0.000	0.402	0.002	0.005	0.014	0.999	67

	BL	Wild	0.83	0.29	0.00	9.40	0.12	0.26	0.63	0.011	0.003	0.000	0.057	0.001	0.004	0.011	0.423	59
	BL	Free	0.65	0.17	0.00	4.48	0.10	0.30	0.67	0.024	0.007	0.000	0.176	0.001	0.013	0.031	0.752	41
	IF	Novel	0.41	0.09	0.00	2.83	0.09	0.22	0.49	0.026	0.013	0.000	0.565	0.001	0.005	0.017	1.072	57
	IF	Wild	0.58	0.19	0.00	7.43	0.09	0.22	0.57	0.051	0.030	0.000	1.265	0.001	0.005	0.027	2.178	58
	IF	Free	0.85	0.40	0.00	19.28	0.10	0.22	0.53	0.038	0.015	0.000	0.534	0.002	0.010	0.028	1.837	69
Hayed	IF	Novel	0.39	0.16	0.00	7.40	0.05	0.09	0.18	0.047	0.035	0.000	1.822	0.001	0.004	0.010	2.480	74
Ortho-P All																		
Grazed	BL	Novel	2.44	0.15	0.12	7.66	0.95	2.16	3.46	0.243	0.045	0.000	4.176	0.022	0.084	0.224	28.476	117
	BL	Wild	3.07	0.23	0.40	13.31	1.26	2.52	4.63	0.194	0.040	0.000	3.129	0.009	0.069	0.239	18.233	94
	BL	Free	2.65	0.25	0.34	8.82	0.93	1.88	3.68	0.295	0.065	0.000	2.922	0.026	0.078	0.281	20.921	71
	IF	Novel	1.06	0.09	0.06	4.50	0.34	0.82	1.48	0.088	0.018	0.000	1.068	0.005	0.017	0.054	8.505	97
	IF	Wild	1.04	0.10	0.00	5.49	0.35	0.88	1.34	0.103	0.017	0.000	0.718	0.004	0.022	0.107	10.349	100
	IF	Free	1.57	0.12	0.14	7.65	0.60	1.22	2.22	0.147	0.021	0.000	1.314	0.017	0.055	0.139	17.035	116
Hayed	IF	Novel	0.41	0.04	0.00	3.43	0.09	0.26	0.57	0.027	0.004	0.000	0.236	0.001	0.007	0.033	3.416	126
Ortho-P No Cattle																		
Grazed	BL	Novel	2.00	0.19	0.50	7.66	0.82	1.47	2.64	0.181	0.034	0.000	1.439	0.023	0.110	0.222	12.116	67
	BL	Wild	2.57	0.29	0.40	13.31	1.07	1.70	3.63	0.136	0.025	0.000	0.974	0.009	0.071	0.178	7.998	59
	BL	Free	2.05	0.25	0.42	6.18	0.84	1.42	3.19	0.166	0.043	0.000	1.575	0.028	0.073	0.176	6.808	41
	IF	Novel	0.72	0.11	0.06	4.50	0.22	0.44	0.84	0.059	0.016	0.000	0.606	0.005	0.013	0.038	3.383	57
	IF	Wild	0.83	0.14	0.00	5.49	0.25	0.54	0.93	0.084	0.021	0.000	0.718	0.005	0.020	0.062	4.885	58
	IF	Free	1.04	0.10	0.14	4.65	0.49	0.75	1.43	0.097	0.017	0.000	0.710	0.018	0.047	0.111	6.697	69
Hayed	IF	Novel	0.35	0.06	0.00	3.43	0.04	0.15	0.36	0.022	0.005	0.000	0.236	0.001	0.005	0.014	1.628	74
Ortho-P With Cattle																		
Grazed	BL	Novel	3.01	0.23	0.12	6.44	1.96	2.89	4.06	0.327	0.094	0.000	4.176	0.018	0.073	0.281	16.361	50
	BL	Wild	3.90	0.35	0.65	9.32	2.24	3.55	5.53	0.292	0.097	0.000	3.129	0.007	0.045	0.312	10.235	35
	BL	Free	3.46	0.46	0.34	8.82	1.52	2.80	4.98	0.470	0.138	0.000	2.922	0.011	0.095	0.606	14.114	30
	IF	Novel	1.53	0.13	0.10	4.20	0.93	1.41	2.05	0.128	0.037	0.000	1.068	0.007	0.022	0.116	5.122	40
	IF	Wild	1.32	0.11	0.09	3.56	0.93	1.19	1.61	0.130	0.028	0.000	0.668	0.003	0.038	0.251	5.464	42
	IF	Free	2.36	0.21	0.21	7.65	1.44	2.00	3.00	0.220	0.045	0.000	1.314	0.015	0.087	0.268	10.338	47
Hayed	IF	Novel	0.50	0.05	0.01	1.51	0.24	0.39	0.73	0.034	0.006	0.000	0.154	0.004	0.017	0.058	1.789	52
Total N All																		
Grazed	BL	Novel	2.53	0.25	0.53	8.71	1.22	2.40	3.31	0.220	0.041	0.000	0.996	0.031	0.103	0.348	9.005	41
	BL	Wild	3.79	0.52	0.50	14.32	1.52	3.26	4.36	0.196	0.047	0.000	1.076	0.008	0.094	0.236	7.070	36
	BL	Free	2.84	0.34	0.58	8.42	1.36	2.64	4.08	0.262	0.066	0.001	1.312	0.042	0.153	0.324	6.807	26
	IF	Novel	2.67	0.28	0.79	7.24	1.40	2.43	3.78	0.288	0.080	0.000	2.084	0.024	0.088	0.391	8.629	30
	IF	Wild	3.02	0.32	0.79	11.74	1.67	2.83	3.55	0.332	0.068	0.001	1.460	0.019	0.103	0.525	13.296	40
	IF	Free	2.83	0.22	0.50	6.77	1.83	2.59	3.72	0.309	0.058	0.002	1.300	0.024	0.119	0.562	13.292	43
Hayed	IF	Novel	2.91	0.61	0.50	30.85	1.24	2.05	3.08	0.228	0.053	0.001	1.819	0.016	0.046	0.295	11.406	50
Total N No Cattle																		
Grazed	BL	Novel	2.56	0.30	0.63	8.71	1.21	2.40	3.35	0.271	0.049	0.005	0.996	0.041	0.165	0.424	8.687	32
	BL	Wild	3.34	0.50	0.50	14.14	1.48	3.13	4.12	0.227	0.055	0.000	1.076	0.009	0.114	0.287	6.812	30
	BL	Free	2.54	0.26	0.92	4.31	1.36	2.55	3.99	0.304	0.074	0.004	1.312	0.055	0.187	0.358	6.691	22
	IF	Novel	2.48	0.31	0.79	7.24	1.39	2.19	3.45	0.338	0.093	0.000	2.084	0.033	0.208	0.463	8.443	25
	IF	Wild	2.80	0.39	0.79	11.74	1.38	2.44	3.36	0.422	0.081	0.002	1.460	0.050	0.268	0.658	13.078	31
	IF	Free	2.62	0.21	0.50	5.94	1.48	2.49	3.44	0.359	0.066	0.002	1.300	0.037	0.218	0.652	12.928	36
Hayed	IF	Novel	3.24	0.77	0.67	30.85	1.20	2.28	3.51	0.288	0.065	0.002	1.819	0.022	0.123	0.399	11.218	39

			Total N With Cattle															
Grazed	BL	Novel	2.41	0.42	0.53	4.46	2.17	2.40	2.98	0.035	0.009	0.000	0.079	0.008	0.043	0.053	0.318	9
	BL	Wild	6.06	1.71	3.22	14.32	3.68	4.40	6.35	0.043	0.015	0.004	0.093	0.006	0.039	0.077	0.258	6
	BL	Free	4.52	1.61	0.58	8.42	2.31	4.55	6.74	0.029	0.024	0.001	0.102	0.002	0.007	0.056	0.116	4
	IF	Novel	3.63	0.49	2.67	5.38	2.78	3.49	3.83	0.037	0.016	0.005	0.091	0.006	0.033	0.051	0.187	5
	IF	Wild	3.77	0.40	1.54	5.47	3.08	3.61	4.63	0.024	0.013	0.001	0.124	0.005	0.011	0.019	0.218	9
	IF	Free	3.91	0.69	1.83	6.77	2.14	3.86	5.28	0.052	0.015	0.002	0.113	0.019	0.049	0.081	0.364	7
Hayed	IF	Novel	1.76	0.22	0.50	3.03	1.24	1.80	2.10	0.017	0.005	0.001	0.054	0.005	0.013	0.023	0.188	11
			Total P All															
Grazed	BL	Novel	2.00	0.22	0.06	5.99	0.83	1.84	2.61	0.169	0.034	0.000	0.863	0.022	0.078	0.186	6.942	41
	BL	Wild	3.34	0.48	0.10	14.35	0.95	3.22	4.93	0.183	0.051	0.000	1.259	0.010	0.069	0.175	6.587	36
	BL	Free	2.24	0.37	0.10	7.17	0.85	1.73	3.19	0.226	0.069	0.000	1.682	0.026	0.108	0.234	5.868	26
	IF	Novel	1.29	0.23	0.14	5.60	0.43	0.91	1.63	0.123	0.035	0.000	0.785	0.011	0.032	0.163	3.692	30
	IF	Wild	1.20	0.19	0.23	6.99	0.50	0.89	1.44	0.140	0.037	0.000	0.959	0.006	0.033	0.146	5.590	40
	IF	Free	1.41	0.18	0.18	4.74	0.56	0.87	2.13	0.144	0.035	0.000	1.106	0.015	0.054	0.163	6.207	43
Hayed	IF	Novel	0.53	0.07	0.05	2.26	0.21	0.36	0.71	0.041	0.011	0.000	0.369	0.003	0.010	0.046	2.068	50
			Total P No Cattle															
Grazed	BL	Novel	1.94	0.25	0.50	5.99	0.81	1.59	2.53	0.207	0.041	0.004	0.863	0.042	0.130	0.339	6.623	32
	BL	Wild	3.06	0.53	0.10	14.35	0.83	1.90	4.90	0.210	0.060	0.000	1.259	0.013	0.074	0.272	6.290	30
	BL	Free	2.19	0.35	0.46	5.99	0.87	1.73	3.19	0.260	0.079	0.003	1.682	0.037	0.137	0.340	5.721	22
	IF	Novel	1.13	0.26	0.14	5.60	0.40	0.67	1.19	0.143	0.041	0.000	0.785	0.012	0.044	0.188	3.583	25
	IF	Wild	1.14	0.24	0.23	6.99	0.44	0.69	1.09	0.177	0.046	0.000	0.959	0.018	0.074	0.205	5.483	31
	IF	Free	1.23	0.17	0.18	4.44	0.55	0.78	1.66	0.166	0.041	0.000	1.106	0.022	0.061	0.211	5.972	36
Hayed	IF	Novel	0.55	0.08	0.05	2.26	0.21	0.36	0.72	0.052	0.014	0.000	0.369	0.004	0.016	0.054	2.021	39
			Total P With Cattle															
Grazed	BL	Novel	2.19	0.54	0.06	4.46	0.96	2.27	3.53	0.035	0.010	0.000	0.078	0.003	0.035	0.059	0.319	9
	BL	Wild	4.77	0.92	3.20	9.03	3.22	3.91	5.35	0.050	0.018	0.001	0.103	0.003	0.049	0.091	0.297	6
	BL	Free	2.49	1.61	0.10	7.17	0.42	1.34	4.55	0.037	0.036	0.000	0.145	0.000	0.001	0.074	0.148	4
	IF	Novel	2.09	0.36	1.24	3.05	1.44	1.93	2.81	0.022	0.011	0.003	0.063	0.004	0.012	0.028	0.110	5
	IF	Wild	1.42	0.17	0.45	2.11	1.32	1.54	1.71	0.012	0.008	0.000	0.072	0.001	0.006	0.006	0.107	9
	IF	Free	2.35	0.61	0.38	4.74	0.76	2.45	3.49	0.034	0.011	0.000	0.080	0.008	0.031	0.054	0.235	7
Hayed	IF	Novel	0.43	0.13	0.09	1.61	0.20	0.35	0.46	0.004	0.001	0.000	0.017	0.001	0.002	0.007	0.047	11

* Treatments are forage management, fertilizer (BL organic as broiler litter & IF as inorganic), and three fescue-endophyte associations. Hayed treatments were not grazed; the cattle and no cattle data are for periods where cattle were present or absent in other paddocks.

† SE standard error; Min minimum; Max maximum, Q1 25th percentile; Q3 75th percentile. Concentration does not have a Sum column because it does not apply.

†† Obs. Represent number of observation for both concentration and load data.

Supplemental table S4

Statistical summary for total annual nutrient load (kg ha⁻¹) by treatment from April 2002 through December 2009.

Forage management	Grazed			Grazed			Hayed	Grazed	
Fertilizer	Organic			Inorganic			Inorganic	Organic	Inorganic
Fescue	Novel	Wild	Free	Novel	Wild	Free	Novel	All	All
Nutrient & Statistics									
Nitrate-N (2002-2009)									
Mean	0.17	0.08	0.15	0.12	0.92	0.36	0.98	0.13	0.47
SE	0.05	0.02	0.05	0.05	0.55	0.22	0.82	0.03	0.20
Minimum	0.02	0.01	0.00	0.01	0.01	0.02	0.02	0.00	0.01
Maximum	0.47	0.18	0.43	0.46	4.15	1.90	6.74	0.47	4.15
Total	1.37	0.61	1.21	0.94	7.33	2.91	7.86	3.18	11.18
Ammonium-N (2002-2009)									
Mean	0.64	0.29	0.39	0.22	0.38	0.34	0.66	0.44	0.32
SE	0.47	0.18	0.22	0.08	0.18	0.13	0.38	0.18	0.08
Minimum	0.02	0.01	0.00	0.00	0.01	0.02	0.02	0.00	0.00
Maximum	3.87	1.57	1.87	0.66	1.58	1.10	2.49	3.87	1.58
Total	5.08	2.36	3.14	1.79	3.07	2.72	5.32	10.57	7.58
Ortho-P (2002-2009)									
Mean	3.57	2.38	2.78	1.08	1.31	2.09	0.45	2.91	1.49
SE	1.14	0.69	1.05	0.31	0.48	0.67	0.16	0.55	0.29
Minimum	0.17	0.01	0.00	0.01	0.01	0.06	0.03	0.00	0.01
Maximum	9.92	5.77	9.37	2.38	3.56	5.96	1.32	9.92	5.96
Total	28.54	19.00	22.25	8.61	10.50	16.73	3.64	69.79	35.84
Total N (2007-2009)									
Mean	2.94	2.36	2.55	2.99	4.03	4.29	3.42	2.62	3.77
SE	2.43	2.07	2.05	2.53	3.42	3.60	2.88	1.10	1.62
Minimum	0.12	0.01	0.00	0.01	0.03	0.10	0.09	0.00	0.01
Maximum	7.78	6.49	6.61	8.02	10.84	11.46	9.15	7.78	11.46
Total	8.83	7.07	7.65	8.96	12.09	12.88	10.26	23.55	33.93
Total P (2007-2009)									
Mean	2.23	2.21	2.17	1.31	1.75	2.03	0.64	2.20	1.70
SE	1.36	1.72	1.52	0.90	1.30	1.47	0.57	0.77	0.63
Minimum	0.13	0.01	0.00	0.01	0.01	0.06	0.02	0.00	0.01
Maximum	4.78	5.59	5.09	3.04	4.28	4.91	1.78	5.59	4.91
Total	6.68	6.62	6.51	3.92	5.26	6.10	1.92	19.80	15.28

Supplemental table S5

Total annual nutrient load (kg ha⁻¹) for grazed paddocks with inorganic and organic fertilization pooled across fescue endophyte associations and inorganically fertilized hayed paddocks under novel endophyte fescue. *

Nutrient	Treatment	Year								
		2002	2003	2004	2005	2006	2007	2008	2009	Total
						kg ha ⁻¹				
Nitrate-N	Grazed Organic	0.87	0.27	0.66	0.18	0.07	0.34	0.03	0.76	3.18
	Grazed Inorganic	6.52	0.37	0.80	0.31	0.06	0.18	0.03	2.90	11.18
	Hay Inorganic	6.74	0.19	0.49	0.10	0.02	0.04	0.02	0.27	7.86
	All	14.13	0.83	1.95	0.59	0.15	0.56	0.08	3.93	22.22
Ammonium-N	Grazed Organic	0.91	0.39	0.68	7.30	0.14	0.15	0.03	0.97	10.57
	Grazed Inorganic	3.34	0.53	0.84	1.00	0.19	0.17	0.02	1.49	7.58
	Hay Inorganic	2.31	0.12	0.15	0.18	0.03	0.02	0.02	2.49	5.32
	All	6.56	1.04	1.67	8.48	0.36	0.34	0.07	4.95	23.47
Ortho-P	Grazed Organic	4.56	8.52	25.05	12.59	1.79	5.13	0.18	11.98	69.79
	Grazed Inorganic	1.79	4.25	11.90	4.78	1.09	3.09	0.07	8.87	35.84
	Hay Inorganic	0.24	0.62	0.91	0.33	0.06	0.14	0.03	1.32	3.64
	All	6.59	13.39	37.86	17.7	2.94	8.36	0.28	22.17	109.27
Total N	Grazed Organic	ND	ND	ND	ND	ND	2.54	0.13	20.88	23.55
	Grazed Inorganic	ND	ND	ND	ND	ND	3.47	0.14	30.32	33.93
	Hay Inorganic	ND	ND	ND	ND	ND	1.01	0.09	9.15	10.26
	All	ND	ND	ND	ND	ND	7.02	0.36	60.35	67.74
Total P	Grazed Organic	ND	ND	ND	ND	ND	4.20	0.13	15.47	19.80
	Grazed Inorganic	ND	ND	ND	ND	ND	2.98	0.07	12.23	15.28
	Hay Inorganic	ND	ND	ND	ND	ND	0.13	0.02	1.78	1.92
	All	ND	ND	ND	ND	ND	7.31	0.22	29.48	37.00

* ND Not determined. Estimates include values for events where data were missing (see text for explanation)