Runoff under natural rainfall from small tall fescue catchments in the Georgia Piedmont USA

Dinku M. Endale*, Alan J. Franzluebbers, John A. Stuedemann, Dwight S. Seman, Dorcas H. Franklin, Harry H. Schomberg

Dinku M. Endale is an agricultural engineer with the USDA Agricultural Research Service, Tifton, Georgia. **Alan J. Franzluebbers** is an ecologist with the USDA Agricultural Research Service, Raleigh, North Carolina. **John A. Stuedemann** is a retired Animal Scientist with the USDA Agricultural Research Service, Watkinsville, Georgia. **Dwight S. Seman** is an animal scientist with the USDA Agricultural Research Service, Lexington, Kentucky. **Dorcas H. Franklin** is a soil scientist with the University of Georgia, Crop and Soil Sciences Dept., Athens, Georgia. **Harry H. Schomberg** is an ecologist with the USDA Agricultural Research Service, Beltsville, Maryland.

* Corresponding author: Dinku.Endale@ars.usda.gov

Phone: 229-386-3893; Fax: 229-386-7225

SUPPLEMENTAL MATERIAL

Pages -12; Tables – 2; Figures - 4

Materials and Methods

Standard Precipitation Index and drought classification. We used the Standard Precipitation Index (SPI) approach (McKee et al. 1993; Edwards and McKee 1997; Hayes and Svoboda 1999; NDMC 2012a) to compare actual rainfall during the study aggregated at 1-, 3-, 6-, 9-, and 12-month time scales to the probability of rainfall for the same time period based on 75 years of monthly rainfall records (1937-2011). A 1-month time scale analysis utilizes the total precipitation for that month, while a 3-month considers the month of interest and the two previous months, etc. The SPI approach has received widespread acceptance in recent years due to, among other traits, its simplicity (requiring only precipitation data), flexibility (computation at different time scales and hence use in a range of meteorological, hydrological and agricultural applications) and its probabilistic nature (Jain et al. 2010; Hayes 2000 and 2012). It is being used by the National Drought Mitigation and National Climatic Data Centers to table one- and multiple-month drought classifications across the United States. The developers recommend a minimum of 30 years of good quality monthly rainfall data to derive the SPI. The monthly rainfall values are first fitted into a suitable distribution such as the Gamma distribution. The estimated parameters are then used for calculating cumulative probability distribution for the time scale of interest and subsequently modified to include the common no rainfall occurrences. The ensuing cumulative probability is then transformed to the standard normal variable with mean of zero and variance of one. The SPI is the number of standard deviations (negative representing dry and positive wet conditions) the rainfall of interest is from the zero mean. For practical purposes SPI values encompassing the extremely dry to extremely wet spectrum have been classified

into categories (McKee et al. 1993; NDMC 2012b) representing intensities of dryness and wetness as: extremely dry (< -2.0), severely dry (-1.99 to -1.5), moderately dry (-1.49 to -1.0), near normal (-0.99 to 0.99), moderately wet (1.0 to 1.49), very wet (1.5 to 1.99), and extremely wet (> 2.0).

Data Analyses. Data analyses for runoff in mm and normalized as percent of event rainfall (referred to as percent runoff) were carried out in three phases. In the first phase, we developed a methodology to estimate missing runoff values. First, using all available runoff data, linear regression was performed between all paddock-pairs. Following that, we identified for each paddock up to three other paddocks that gave the greatest group of coefficient of determination (r^2). We then plotted the data from the three chosen paddock-pairs and checked if non-linear regression would improve any of the correlations. If so, we replaced a linear model with a non-linear one. Of the finally selected models, 75% were linear while 25% were non-linear, and 96% had $r^2 \geq 0.8$ while 62% had $r^{2\geq}$ 0.9. Two models had r^2 of 0.71 and 0.74. A missing runoff value for a paddock was then estimated using the model from the paddock-pair that produced the greatest correlation if there was data from the corresponding paddock for the particular event; if not, the model and data from paddock-pair giving the next greatest correlation was used, etc. Usually no more than 2 steps were needed to estimate missing runoff data.

In the second phase of data analyses, we examined possible correlations between runoff and landscape attributes generated from the detailed GPS/GIS-based survey because of the degree of runoff variability observed among individual paddocks. The ratio between the largest and smallest overall paddock mean runoff using the dataset with missing values, and that with estimate for missing values, varied from 3.6 to 4.2. First a

stepwise regression was performed using rain, area-weighted slope, and lengths of each of the six categories of flow-path orders or some of them. Next a linear regression was performed between runoff and length of each of the six flow path order categories, cumulative percentage area by slope class of 1 to 9 in increments of 1%, and area-weighted slope. Following that, a regression of runoff against a combination of area-weighted slope and length of one of the six flow path order categories, and a combination of flow path order 1 (FPO1) and cumulative percentage area up to slope class 2 (CPS2) was performed. The latter was done because, individually, these two variables showed greater correlation with runoff than the other considered variables. Finally in this phase, we performed factor analysis using 23 variables describing rainfall, runoff, and landscape attributes and identified event rainfall amount, FPO1, CPS2, and area-weighted slope (AWS) as the best variables to account for the effects of landscape on runoff variability. Two of these, FPO1 and CPS2, were variables that showed greater correlation with runoff in the analyses performed earlier. We, therefore, used these four variables as covariates in the third phase, the statistical analysis, to constrain the analysis into identifying treatment effects only as described in the main article.

Supplemental Table 1

Runoff flow path lengths and slope attributes by paddock from detailed GPS/GIS-based survey.

Landscape	Paddock†													
Attribute‡	BF12	BW10	IM11	BF5	IMHA	BM9	BW4	IW2	IW8	IM6	IF3	IMHB	IF7	BM1
	meter													
FPO1	904	750	1148	1587	1189	1099	1943	1953	1334	1425	1133	2136	1134	2540
FPO2	570	362	457	501	598	596	864	754	619	568	370	840	500	839
FPO3	254	200	180	181	156	183	276	208	241	241	119	188	120	267
FPO4	106	26	93	107	39	48	111	24	33	135	34	85	24	46
FPO5	0	0	0	33	0	0	0	0	42	30	0	79	0	0
TFPL	1833	1337	1844	2409	1977	1926	3194	2939	2269	2400	1656	3325	1779	3692
	percent													
CPS1	1.5	7.5	3.1	0.4	7.0	0.9	9.6	2.2	5.0	0.6	2.1	1.2	3.8	3.9
CPS2	19.1	36.7	33.9	13.2	18.9	12.5	23.0	10.0	16.0	11.6	15.6	6.5	9.9	13.4
CPS3	36.3	65.8	52.3	39.9	29.6	36.7	40.0	24.0	34.4	51.1	43.7	26.6	24.2	26.9
CPS4	61.6	78.2	67.7	68.6	48.2	52.6	56.5	40.7	52.7	94.3	61.1	62.1	62.8	43.8
CPS5	83.5	87.7	82.9	94.2	64.4	62.3	69.8	64.3	71.4	100.0	73.7	76.9	88.7	58.0
CPS6	90.6	95.6	95.3	100.0	79.6	83.9	85.3	84.1	95.3	*	84.5	100.0	95.0	79.3
CPS7	95.0	99.5	100.0	*	95.1	100.0	93.4	95.0	96.9	*	94.4	*	97.8	94.2
CPS8	99.6	100.0	*	*	98.1	*	98.6	100.0	100.0	*	100.0	*	99.6	98.6
CPS9	100.0	*	*	*	100.0	*	100.0	*	*	*	*	*	100.0	100.0
	percent													
AWS	4.1	3.3	3.6	3.8	4.6	4.5	4.2	4.8	4.3	3.4	4.3	4.3	4.2	4.8

† Columns are arranged by ascending order (left to right) of paddock geometric mean runoff. Paddock designation: 1st letter – fertilizer treatment (B – broiler litter, and I – inorganic fertilizer); 2nd letter – fescue treatment (F – Free, W –Wild, and M - MaxQ). 3rd letter or numerals (H – hayed, 1 to 12 grazed paddock numbers); 4th letter – hayed paddocks A & B. Cells with asterisks indicate absence of the corresponding attribute.

‡ FPO1-FPO5. Runoff flow path order 1 to 5
TFPL. Total flow path length
CPS1 to CPS9. Cumulative percentage area of paddock for slope class 1 to 9
AWS. Area-weighted slope in percent

Supplemental Table 2

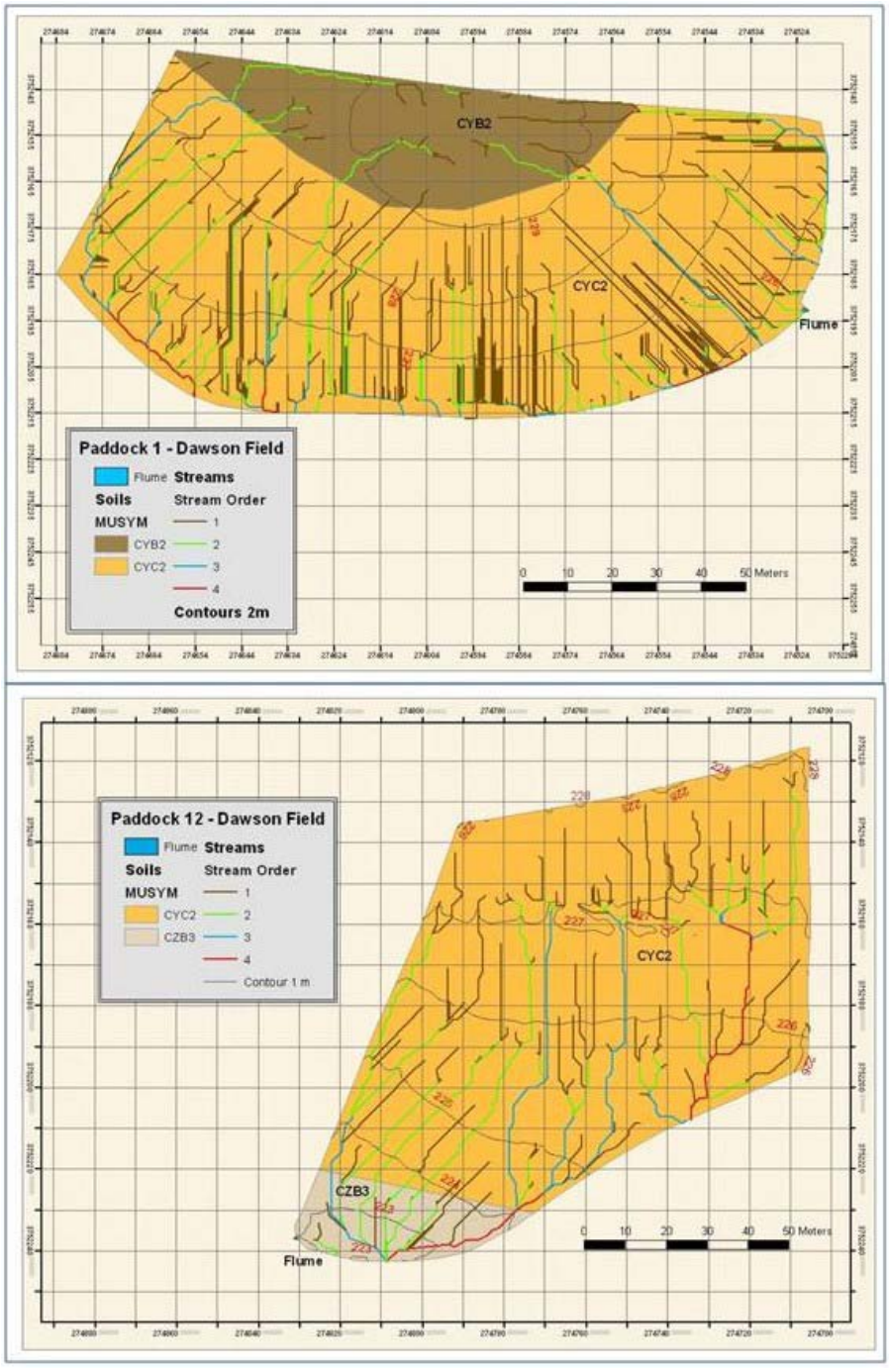
Summary of two-sample t-test for LN-transformed runoff and percent runoff dataset with missing values (Missing) and dataset with missing values filled in through regression (Filled) †

	Missing			Filled			
Paddock	Mean	SE	n	Mean	SE	n	Pr > F
Runoff							
BM1	1.874	0.129	67	1.848	0.121	77	0.886
IW2	1.260	0.248	34	1.276	0.154	77	0.956
IF3	1.618	0.153	69	1.676	0.144	77	0.783
BW4	1.259	0.150	65	1.335	0.138	77	0.711
BF5	1.090	0.264	25	1.124	0.137	77	0.907
IM6	1.448	0.152	73	1.392	0.147	77	0.793
IF7	1.696	0.301	17	1.537	0.128	77	0.632
IW8	1.358	0.186	58	1.366	0.152	77	0.972
BM9	1.187	0.138	70	1.162	0.132	77	0.896
BW10	0.853	0.131	62	0.774	0.115	77	0.650
IM11	0.878	0.131	59	0.879	0.114	77	0.994
BF12	0.814	0.143	61	0.824	0.126	77	0.957
IMHA	1.105	0.127	58	1.228	0.111	77	0.470
IMHB	1.676	0.303	25	1.876	0.135	77	0.551
Percent runoff							
BM1	2.537	0.127	67	2.528	0.115	77	0.955
IW2	1.586	0.282	34	1.678	0.167	77	0.772
IF3	2.162	0.166	69	2.235	0.154	77	0.749
BW4	1.670	0.172	65	1.764	0.157	77	0.686
BF5	1.338	0.296	25	1.460	0.159	77	0.708
IM6	1.881	0.169	73	1.803	0.166	77	0.743
IF7	2.135	0.311	17	2.061	0.140	77	0.824
IW8	1.732	0.205	58	1.770	0.170	77	0.887
BM9	1.560	0.161	70	1.530	0.152	77	0.895
BW10	1.155	0.146	62	1.039	0.129	77	0.554
IM11	1.193	0.148	59	1.203	0.127	77	0.960
BF12	1.044	0.163	61	1.044	0.143	77	1.000
IMHA	1.554	0.141	58	1.733	0.120	77	0.333
IMHB	2.102	0.331	25	2.479	0.145	77	0.304

† SE – standard error. Percent runoff is runoff normalized with respect to event rainfall (runoff as percent of event rainfall). The row data were transformed as LN(runoff+1) and LN(percent runoff+1) for statistical analysis. In the Filled section, n of 77 includes events with zero runoff for the 77 storms that produced runoff in one or more paddocks at the same time.

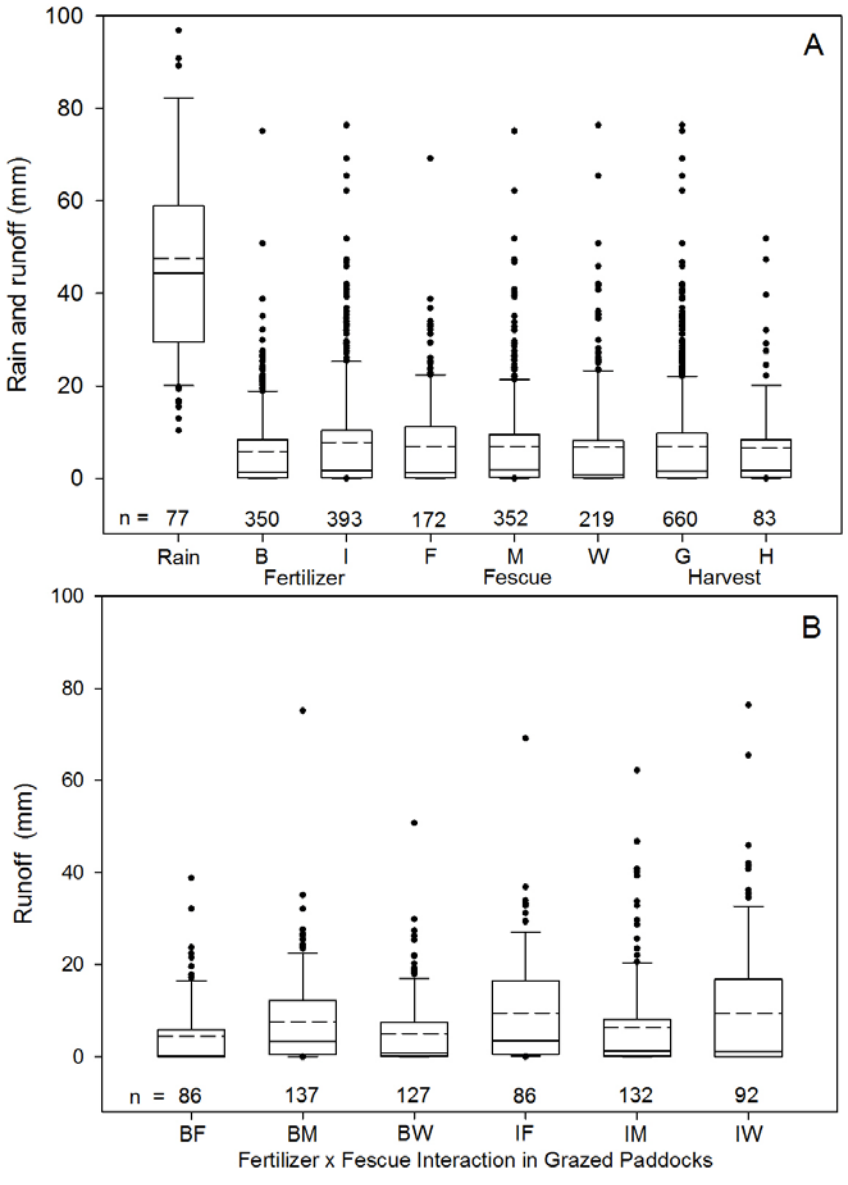
Supplemental Figure 1

GPS/GIS analysis-based soil, elevation contour, and stream order (runoff flow path order) map for paddock 1 (BM1 – broiler litter fertilization and MaxQ tall fescue) and paddock 12 (BF12 – broiler litter and Free tall fescue). Paddock 1 has ~2.8 times the stream order 1 (FPO1 - runoff flow path order 1) and ~1.5 the stream order 2 length as that of Paddock 12. A line of old terrace remnants can be discerned in the upper and middle part of paddock 12 from where stream order 1 feeds into stream order 2.



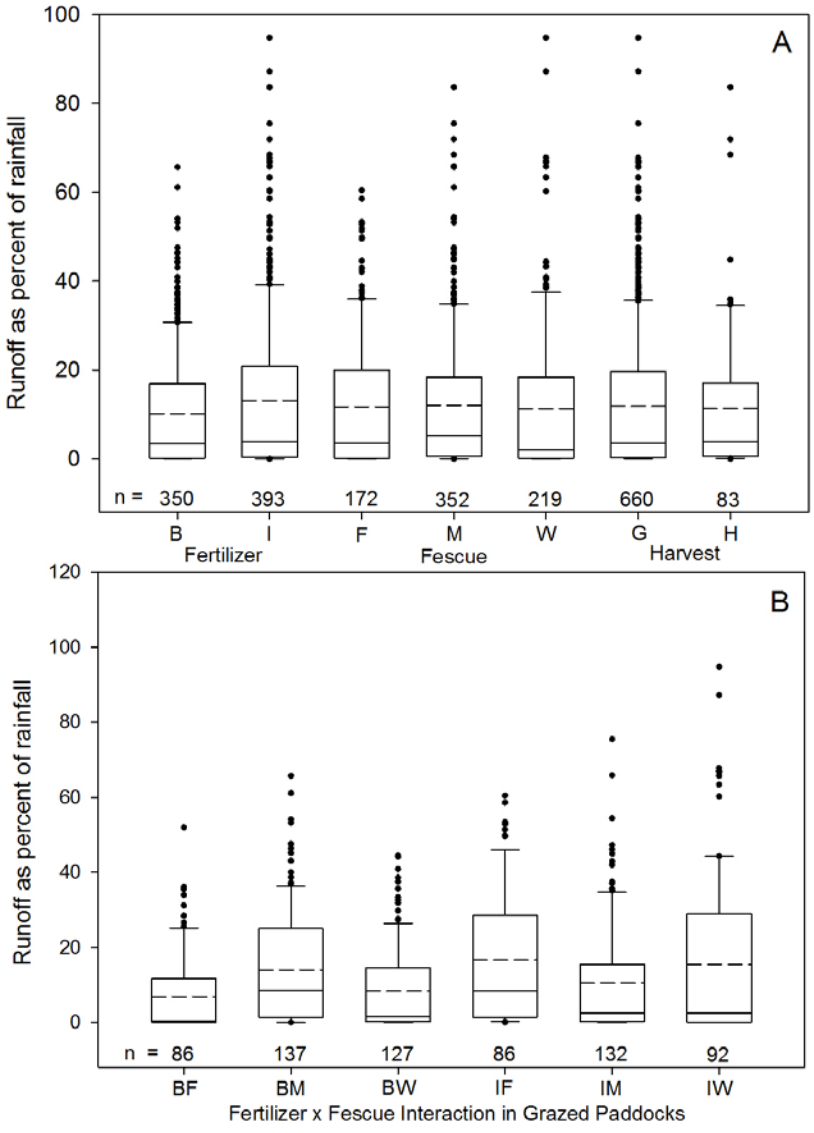
Supplemental Figure 2

Box plots for runoff by treatment using the untransformed dataset with missing values filled in through regression. The mean and median values are represented by the dashed and solid lines, respectively, inside the boxes that bound the 25th and 75th percentile values. The dots represent values outside of the 10th and 90th percentile (represented by whiskers).



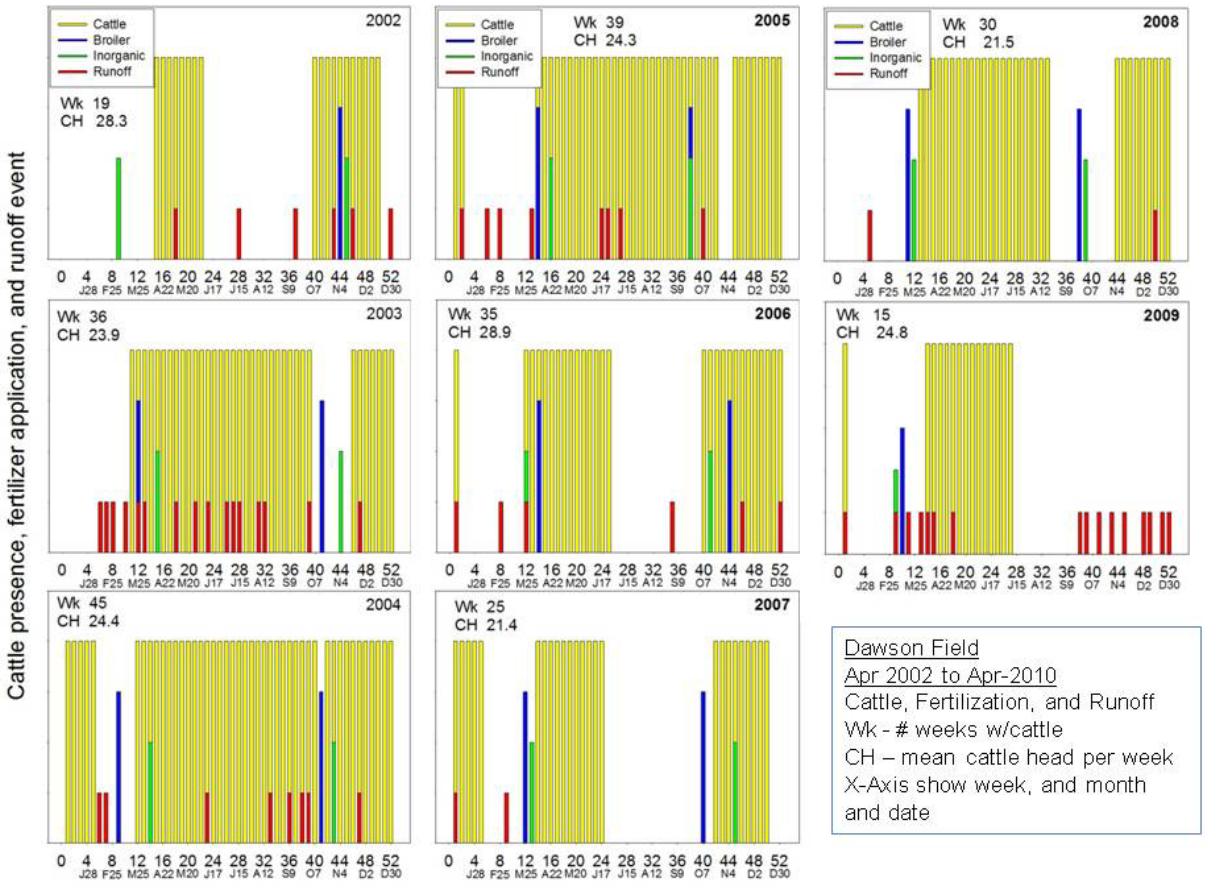
Supplemental Figure 3

Box plots for runoff as percent of event rainfall by treatment using the untransformed dataset with missing values filled in through regression. The mean and median values are represented by the dashed and solid lines, respectively, inside the boxes that bound the 25th and 75th percentile values. The dots represent values outside of the 10th and 90th percentile (represented by whiskers).



Supplemental Figure 4

Cattle presence, and fertilization and runoff events, April 2002 to April 2010 at Dawson Field paddocks. There were no cattle and no fertilization in 2010; but there were 4 runoff events through April 2010 - (study ended April 2010).



REFERENCES

Edwards, D. C., and T.B. McKee. 1997, Characteristics of 20th century drought in the United States at multiple time scales: Atmospheric Science Paper No. 634. Climatology Report No. 97-2. Department of Atmospheric Science, Colorado State University, Fort Collins, CO.

Hayes, M.J. 2000. Revisiting the SPI: Clarifying the process. *Drought Network News (1994-2001).* Paper 18. National Drought Mitigation Center, University of Nebraska, Lincoln, NE.

Hayes, M.J. 2012. Comparison of major drought indices. National Drought Mitigation Center, University of Nebraska, Lincoln, NE. Available at http://drought.unl.edu/Planning/Monitoring/ComparisonofIndicesIntro.aspx verified 08-29-2012.

Hayes, M.J., and M.D. Svoboda. 1999. Monitoring the 1996 drought using SPI. Bulletin of American Meteorological Society 80:429–438.

Jain, S.K., A. Sarkar, R. Keshri, and A. Goswami. 2010. Application of meteorological and vegetation indices for evaluation of drought impact: a case study for Rajasthan, India. Natural Hazards 54:643–656.

McKee, T.B., N.J. Doesken, and J. Kleist. 1993. The relationship of drought frequency and duration to time scales: Preprints, 8th Conference on Applied Climatology, p. 179–184.

NDMC (National Drought Mitigation Center). 2012a. Program to calculate Standardized Precipitation Index. National Drought Mitigation Center, University of Nebraska, Lincoln, NE. Available at

http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx Verified 2-18-2013.

NDMC. 2012b. How do I measure drought? National Drought Mitigation Center, University of Nebraska, Lincoln, NE. Available at http://drought.unl.edu/ranchplan/DroughtBasics/WeatherDrought/MeasuringDrought.aspx Verified 2-18-2013.