Comparison of Beef Cattle Grazing Management Practices and their Effects on Runoff Water Quality in Louisiana

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Abstract: Management-intensive grazing (MIG) allows better use of grazed forage crops with short-duration grazing in small paddocks and with this study; the water quality was compared for two grazing management methods. Year-round grazing with MIG and continuous stocking (CS) were compared. Four 0.81-ha plots for two replications of the grazing systems were established. Twenty 0.04 ha (0.1 ac) paddocks, established with power fencing, allowed daily cattle rotation in MIG system. Continuous grazing and MIG used the same stocking rate on each experimental plot (0.81 ha). Each year, two crossbred beef (*Bos taurus*) heifers (390 kg ±12 kg; 12-14 mo at start) were maintained on each plot year-around for 3 yr, with additional yearling heifers added to maintain similar forage availability between stocking methods.

Common bermudagrass (*Cynodon dactylon* [L] Pers.) was grazed in summer and annual ryegrass (*Lolium multiflorum* Lam.) was over-seeded into the sod during October for winter and spring grazing. Forage mass was determined monthly and available forage dry matter (DM) was maintained at approximately 1120 kg DM ha^{-1} Runoff water samples were collected during 42 rainfall events from May 2001 through March 2004. No significant treatment differences ($P > 0.10$) were found in most of the water quality parameters. Runoff as a percentage of the 3-yr average annual rainfall of 1869 mm was 34% for MIG and 42% CS. The average flow-weighted concentrations of soluble reactive phosphorus (SRP) varied from 5.08 mg P L^{-1} (ppm) to 8.22 mg P L^{-1} (ppm) while the NH^{+}_{4}–N ranged from 1.07 mg N L^{-1} (ppm) in year one to 10.11 mg N L^{-1} (ppm) for the second year ($P < 0.05$) for year effect. Total annual average forage production was greater ($P < 0.05$) in the MIG compared to CS with19,796 kg ha^{-1} for MIG vs. 16,964 kg ha^{-1} for CS. Beef production also increased with the MIG system with an annual total beef gain from MIG at 422 kg ha^{-1} y^{-1} vs. CS at 330 kg ha^{-1} yr^{-1}.

Keywords: Best management practices, management intensive grazing, continuous stocking, water quality runoff.

1. INTRODUCTION

Proper grazing management not only increases total productivity but benefits the environment. Several claims exist in the literature that MIG is one of the best production systems available to livestock farmers to protect water quality by reducing runoff and soil erosion [1-2]. Grazing management implies a degree of control over both the animals and the forage sward. Rotational stocking and especially strip-grazing are effective practices to increase herbage utilization efficiency, minimize camping and randomly distribute dung and urine [3]. These ensure that all spots are equally affected and enriched in the long term, especially in intensively managed pastures. Well-managed pastures also act as very large riparian buffers to protect water quality [4].

Management-intensive grazing (MIG) allows better use of grazed forage crops with short-duration grazing in small paddocks [5]. Allen *et al*. [6] defined this form of intensive grazing management as rotational stocking, a method that utilizes recurring periods of grazing and rest among several paddocks in a grazing management unit through-out the time when grazing is allowed. The intensive grazing management is used to increase production per unit area, through a relative increase in stocking rates, grazing pressure and forage utilization. *Continuous stocking* is defined as the continuous, unrestricted grazing of a specific pasture unit of land where animals have unrestricted and uninterrupted access throughout the time when grazing is allowed [6].

Advantages of MIG may include more uniform grazing, better stand maintenance of some plant species, greater animal production per hectare, and increased opportunity for heavy grazing pressures without permanent damage to plants [7, 8]. An increase in pasture productivity and improved excreta distribution with MIG may result in better quality of surface runoff with smaller concentrations of nutrients when compared with other grazing systems [9]. One stated purpose in Louisiana NRCS Prescribed Grazing, Code 528 is to improve or maintain surface and/or subsurface water quality and quantity [10]. Although, MIG is a recommended best management practice in other states [11], the environmental benefits have not been sufficiently documented. To date, researchers have not satisfactorily evaluated the impact of feces

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and urine deposited by grazing animals as additional sources of nutrients in water runoff when comparing MIG (as a best management practice) to continuous stocking.

Grazing livestock redistribute soil minerals by consuming nutrients present in pasture plants and excreting 60-99% of them in feces and urine [12]. The grazing management system impacts soil nutrient distribution while stock density and duration of grazing periods affect distribution of excreta. Short duration, rotational stocking at high density, can significantly improve the uniformity of nutrient redistribution [3, 12] by controlling the time that animals spend on each paddock, while the spatial distribution of these nutrients in continuous grazed grasslands is highly heterogeneous [13].

Mathews *et al*. [14] found that uneven distribution of dung and urine in grazed pastures resulted in gradients in soil P and K concentration, with peak concentration occurring near shade and water. Nutrients excreted primarily in feces, including P, are likely to be concentrated in shallow soil layers beneath the dung patch and at varying distances up to five times the area of the dung patch [15]. Little consideration has been given to the effect of scale and methodology of the research on the processes of mobilization (the process whereby P is transferred from a P source to the runoff) and subsequent concentrations, and loads of P measured in surface runoff [16]. Rainfall intensity affects surface runoff generation as well as concentration of nutrients in runoff [17]. Infiltration excess runoff requires sufficient rainfall intensity and duration for soil infiltration capacity to be overwhelmed, whereas saturation excess runoff may occur at extremely low rainfall intensities [18]. Edwards and Daniel [19] found that the intensity of rainfall was negatively related to concentration (mg L^{-1}) of P and N in runoff, but was positively related to mass lost (kg ha^{-1}) of P and N in runoff.

Pluhar *et al*. [20] compared selected grazing treatments in the Texas rolling plains and showed that grazing caused a significant decline in water infiltration rates with less ground cover and a significant increase in sediment in the runoff, as compared to an ungrazed enclosure. Briske *et al.* [21] noted that experimental evidence does not support implementation of rotational grazing to enhance either production or environmental goals on rangelands. Water quality problems associated with grazing animals tend to be most serious when the total number of animals in a landscape or watershed significantly exceeds the carrying capacity of the land, when poor management practices are used, and when animal operations are in the lower part of the landscape [22].

Grazing animals can also change the characteristics of grassland as a nutrient source. They may alter the type and amount of nutrients that can be mobilized and lost to water by affecting a spatial and chemical re-distribution of nutrients and, sometimes, by causing enough soil physical damage to reduce grass growth [23]. Owens *et al*. [24] noted a 60% increase in sediment loss in an Ohio watershed that experienced summer rotational grazing and winter-feeding as compared to only summer rotational grazing. Also, Owens *et al*. [25] linked increased grazing pressure from a continuous grazing practice to increases in organic N, total organic C, and sediment concentration and transport. Grazing with increased stocking density affects nitrate-N (NO_3-N) loss through leaching because the bulk of the N consumed by the animal is excreted in the urine as urea. Even though most of the excreted N (55-75%) is in the urine, rotational grazing has shown that it provided up to an 80% reduction in loss of N compared to continuous grazing [26].

Stout *et al*. [27] reported that MIG may have a detrimental effect on water quality by increasing the inputs of N and P from dairy cattle urine and feces deposited with high density stocking in grazed area, which can result in increased losses of nutrients *via* leaching and runoff [28]. However, work in Arkansas [29] has shown that for pastures, P losses vary depending on watershed conditions and management with overgrazing contributing significantly to sediment and P losses from the overgrazing.

Brooks *et al*. [30] and Thurow [31] reported that grazing animals could be a significant contributor to nutrient and sediment load in overland flow under conditions of intensive grazing. Losses of P in runoff from pasture measured over a range of stock grazing densities showed no consistent effect on P concentration in the runoff [32]. The distribution of manure in a pasture system can be largely controlled by managing the amount of time cattle spend in certain areas as it can be done with MIG.

The objective of this study was to determine edge of field effect on water quality and to compare the runoff water quality from bermudagrass swards over seeded with ryegrass grazed with beef cattle using intensive-controlled, short duration, *rotational stocking* (MIG) and *continuous stocking* (CS).

2. MATERIALS AND METHODS

2.1. Site Description

Earthen berms (0.6 m high, 1.5 m wide [2 ft high, 5 ft wide]) were established around four 0.81-ha (2 ac) plots for two replications of grazing systems in an established area of common bermudagrass [*Cynodon dactylon* (L.) Pers] on the University of Louisiana at Lafayette Research Farm at Cade, LA [30° 5´ N lat, 91° 53´ W long; 9 m] elevation. All plots were selected with similar topography (2-4 % slope) on Memphis silt loam soil (fine-silty, mixed, thermic Typic Hapludalfs). Prior to initiation of grazing in 2001, a composite soil sample (12 cores, 1.8 cm [0.5 in] diameter) from the upper 15-cm (6 in) layer of each plot was collected and soil P, K, and total C were determined. Soil sampling and analysis (Mehlich 3) showed that soil P levels in all plots averaged (50-70 mg L^{-1} [ppm]) and K (170-200 mg L^{-1} [ppm]); therefore, no additional P or K fertilizer was added during the study.

2.2. Forage Production/Grazing Management

Grazing began according to treatments in July 2001 and continued through March 2004. Two “tester” crossbred beef heifers (*Bos tarus*) (390 kg [±12 kg] mean initial weight each year) remained on each replicate plot year-round, grazing on common bermudagrass (*Cynodon dactylon* [L.] Pers.) during the warm season. Annual ryegrass (*Lolium multiflorum* Lam.) was over seeded on bermudagrass sod during October for winter and spring grazing. During January, the two tester heifers remained on the plots and each consumed approximately 5 kg bermudagrass hay daily. Twenty 0.04-ha grazing paddocks, established with power fencing, allowed daily cattle rotation in the MIG plots. Forage production was measured monthly, and animal numbers were adjusted by put–and-take to maximize utilization of available forage DM and to maintain approximately 1120 kg ha^{-1} DM. Plots were monitored weekly by visual evaluation for forage density and total dry matter availability for grazing and stocking rates were adjusted monthly, after weighing the cattle.

Available forage was determined by hand-clipping the contained forage within five randomly selected 0.19-m^2 subplots to a height 2.5 cm. In the continuous stocking (CS) plots, five quadrats were randomly located throughout the 0.8 ha plot. In the MIG plots, the five quadrats were located within the next ten 0.04 ha paddocks. Samples collected from each quadrat were composited and dried at 60ºC in a forced-draft oven and were ground in a Wiley mill to pass a 1-mm screen for nutritive value analyses of digestibility and crude protein (CP) by NIR. Nutritive value is defined as the chemical composition, digestibility, and nature of digested products of forage [33].

On both treatments, 60 kg N ha^{-1} as ammonium sulfate (28%N) was added in April, June, and August for the warm-season grass production totaling 180 kg ha^{-1}. In November and February, 60kg ha^{-1} as urea (46% N) was used for the ryegrass totaling 120 kg ha^{-1}. This was an annual application total of 300 kg ha^{-1} of N.

All heifers were weighed in early morning every 28 days. Weight change of the two tester heifers was multiplied by the total animals in each rep to determine total beef weight gain per month in that rep. Animal numbers on each plot were adjusted monthly by ‘put and take’ to maximize utilization of available forage and to maintain the appropriate amount of residual forage in each plot. Stocking rate of heifers was adjusted to maintain a similar forage availability of 1120-1344 kg DM ha^{-1} that maintained an average grazing height of 5 cm for the bermudagrass and 12 cm for the ryegrass. This animal management technique was used to maintain a similar grazing pressure between stocking methods. The forage available in the CS plots dictated the minimum number of heifers per plot to maintain the projected forage residue. On the MIG plots, additional heifers in excess of those added to CS were added as available forage allowed. Stocking density [6] ranged from the minimum of one AU ha^{-1} on all replicate plots to as much as 150 AU ha^{-1} in some paddocks of the MIG plots with daily rotation when there was excessive forage growth.

2.3. Runoff Water Sampling

The berms around each plot channeled runoff water to a 0.45 m (1.5 ft) H-flume established on a concrete pad at the lowest elevation. A 3700FR ISCO refrigerated sampler (ISCO Corporation, Lincoln, NE) with bubbler was installed for each plot. The first water collected in the adjacent ISCO model 674 rain gauge triggered the samplers to activate. Four runoff water samples were obtained from each rainfall event beginning when flow reached 2.5 cm (1 in) in depth in the flumes, and subsequently at 7.5, 15, and 30 m^3 (4,000, 8,000, and 12,000 gal) of flow from each plot.

Surface runoff samples were analyzed for total suspended solids (TSS), total combustible solids (TCS), total N, NH_4-N, NO_3/NO_2-N, particulate N (PN), total P, and soluble reactive phosphorus (SRP). For TSS analyses, runoff samples were vacuum-filtered through Whatman (Maid stone, England) 0.45-µm cellulose nitrate membranes placed on 47-mm Fisher brand glass filter holders (Fisher Scientific, Pittsburgh, PA). All water samples were stored in a refrigerator at 4°C (40°F) before analysis and samples were analyzed within 48h. Total N (USEPA Method 351.2, USEPA, 1979) concentration was determined calorimetrically using a Lachat Auto analyzer II (Zellweger Analytics, Milwaukee, WI) on unfiltered samples following a sulfuric acid digestion in a block digester. The concentration of NO_3/NO_2-N (USEPA Method 352.2, USEPA, 1979) was also determined with the Lachat Auto analyzer on water samples passed through a Whatman 934-AH glass microfiber filter. Quality control for the Lachat autoanalyzer was maintained by inclusion of blanks and randomly positioning control standards with differing concentrations, duplicate samples and one quality control sample in each run. Filtered samples were analyzed for SRP by the molybdate blue method [34] and for NH_4–N by the salicylate–hypochlorite method [35].

Nutrient concentrations at 2.5cm (1 in) in flume, 7.5, 15 and 30m^3 (4,000, 8,000, and 12,000 gal) and the corresponding flow values together with the total flow for a rainfall event were used to determine the total load for the rainfall event in g ha^{-1} (lb ac^{-1}). This was achieved using a piecewise linear approximation to the concentration curve based on the available data. Treatment load differences for each parameter are CS minus MIG computed for the pair of plots within a block.

During the spring of 2001, all pastures were managed with continuous stocking (CS) to maintain moderate available forage DM of approximately 1120 kg ha^{-1} (1000 lb ac^{-1}) to establish baseline values for surface runoff quality and quantity. The baseline water sampling was conducted for the verification of replication and plot-within-replication uniformity of runoff, sediment and nutrient concentration [36].

Water quality data are presented both in terms of the concentration of specific nutrients, expressed in mg L^{-1} (ppm), and the total annual load of those nutrients in surface runoff, expressed in kg ha^{-1}. The total mass loss of all the runoff events from a treatment plot during a year was divided by the volume of yearly runoff to calculate yearly flow-weighted concentration for each plot. Yearly runoff volume, loads, and flow-weighted concentrations were averaged across plots and standard deviations were calculated. The flow-weighted concentrations of each nutrient parameter in the total runoff observed were calculated by dividing the mass loss by the total volume of runoff recorded in that period. Since we hoped to see a decrease in water quality parameters with MIG, we are justified in testing the research hypothesis that the mean is lower with MIG than it is with CS. These tests are based on the differences (CS minus MIG) with the null hypothesis that the mean difference is less than or equal to zero versus the research hypothesis that the mean difference is positive (MIG gives lower values. The flow-weighted loads and differences are equal to the total load divided by the total flow with the differences (CS minus MIG) of these, measured in mg L^{-1} (ppm).

Due to varying management systems and time, analyses of variance (ANOVA) were performed assuming a randomized design to determine treatment differences in selected water quality parameters. A probability level < 0.05 was considered significant. All analyses were conducted with JMP Statistics, version 5.0.1 (SAS Institute Inc., 2002). The relationship between CS and MIG with season was analyzed by looking at the difference between the fall/winter months and the spring/summer months difference in nutrient concentration in runoff. The total loads were regressed on the gap (number of days) between the rainfall events. Linear regression was used to determine the relationships between runoff volume and nutrient losses.

3. RESULTS AND DISCUSSION

3.1. Precipitation and Surface Runoff

Annual precipitation (Figure **1**) was higher in years 1 (2001-2002) and 3 (2003-2004) compared to year 2 (2002-2003). Precipitation in year 2 was similar as long-term mean, and 85% of precipitation in years 1 and 2. Precipitation in year 1 and 3 were 118% of long-term mean, respectively (Figure **1**). The average annual precipitation was 1869 mm, about 11% greater than the 20-year annual mean of 1668 mm as recorded at the University Cade Farm weather station. The monthly total rainfall distribution on average was 10% in February, 23% in June, 10% July, and 10% in September, which consisted of 53% of the total annual rainfall. The greatest monthly precipitations were 599 mm, which was 31% of annual precipitation and 510 mm, which was 26 % of annual precipitation in June 2001 and 2003, respectively (Figure **1**) when tropical storms produced over 500 mm in only two days. The

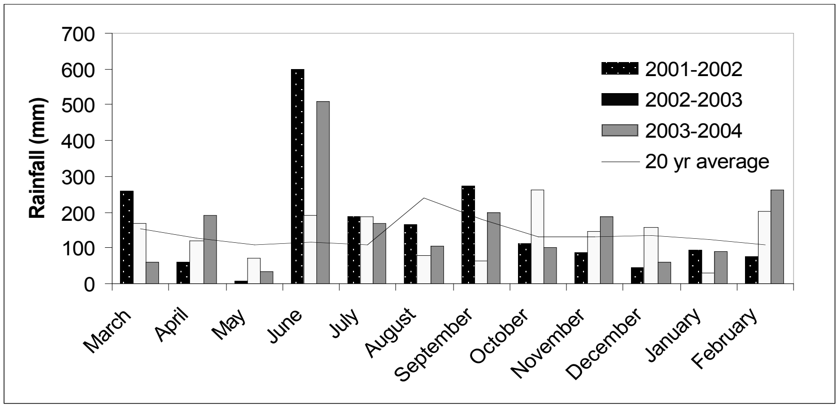


Figure 1: UL-Lafayette Cade research farm monthly and annual precipitation from 2001 to 2004, and 30year mean precipitation (1981-2010).

total surface runoff volume was significantly less ($P < 0.05$) from the MIG plots than from the CS plots. Average annual runoff from the MIG plots was 635mm, while 785mm runoff was recorded from the CS plots which represented 34% and 42% of the total rainfall for the MIG and CS plots, respectively. The total recorded runoff volume for 42 rainfall events was 5626m^3 ha^{-1} from the CS plots and only 4453m^3 ha^{-1} from the MIG plots. The runoff from MIG plots represented 79% of the total volume of runoff from the CS grazing plots.

3.2. Runoff Volume and Nutrient Losses

Nutrient losses *via* runoff are a major source of nutrient pollution to surface water. In this study the mean loss of N and P were classified by runoff volume (Table **1**). During the study period, the number of events with more than 500m^3 ha^{-1} in runoff volume was 5 and 2 in CS and MIG treatment, respectively. Mean runoff losses in those large events from CS and MIG treatment were 3.10Kg ha^{-1} and 2.33Kg ha^{-1} in total N (TN), 0.98Kg ha^{-1} and 0.88Kg ha^{-1} in total P (TP), respectively. In general, mean losses of TSS, TCS, and nutrients were significantly different ($P < 0.05$) in the events with > 200m^3 ha^{-1} of runoff volume compared to the grand total mean losses, whereas the mean losses from < 200m^3 ha^{-1} were not significantly different compared to means from all. Each large runoff volume (greater than 200m^3 ha^{-1}) removed two to five times more in TSS, TCS, TN, NO_3/NO_2-N, NH_4-N, TP, and SRP than the means from small events (smaller than

Table 1: Number of Runoff Events and Mean Losses of TSS, TCS, TN, NO_3/NO_2-N, NH_4-N, TP, and SRP from Continuous Stocking (CS) and Management Intensive Grazing (MIG) plots, UL-Lafayette Cade Farm, 2001-2004

	Runoff volume category (m^3 ha^{-1})	**No. of event**	**TSS**	**TCS**	**TN**	**NO_3/NO_2-N**	**NH_4-N**	**TP**	**SRP**
			kg ha^{-1}						
CS	All	69	6.21b*	2.35b	0.71b	0.15ab	0.05b	0.25c	0.18b
	0-100	35	2.18b	0.63c	0.17c	0.04b	0.01b	0.07d	0.05d
	100-200	15	4.02b	1.90bc	0.70bc	0.19ab	0.04b	0.23bcd	0.18bc
	200-500	14	16.85a	5.93a	1.21b	0.29a	0.07b	0.46b	0.36a
	>500	5	11.20a	5.66ab	3.10a	0.39a	0.27a	0.98a	0.58a
3-yr mean Total Load			70.42	26.50	8.15	1.72	0.54	2.87	2.08
MIG	All	70	6.44b	2.18b	0.65b	0.12b	0.04b	0.22b	0.15c
	0-100	47	1.64b	0.62b	0.25b	0.07b	0.01b	0.09b	0.07d
	100-200	6	7.61ab	2.88ab	0.56ab	0.07b	0.06b	0.18b	0.15bc
	200-500	15	19.30a	5.90a	1.73a	0.27a	0.12a	0.58a	0.31b
	>500	2	19.07a	8.94a	2.33a	0.25ab	0.04ab	0.88a	0.82a
3-yr mean Total Load			72.34	24.35	7.60	1.38	0.49	2.62	1.76

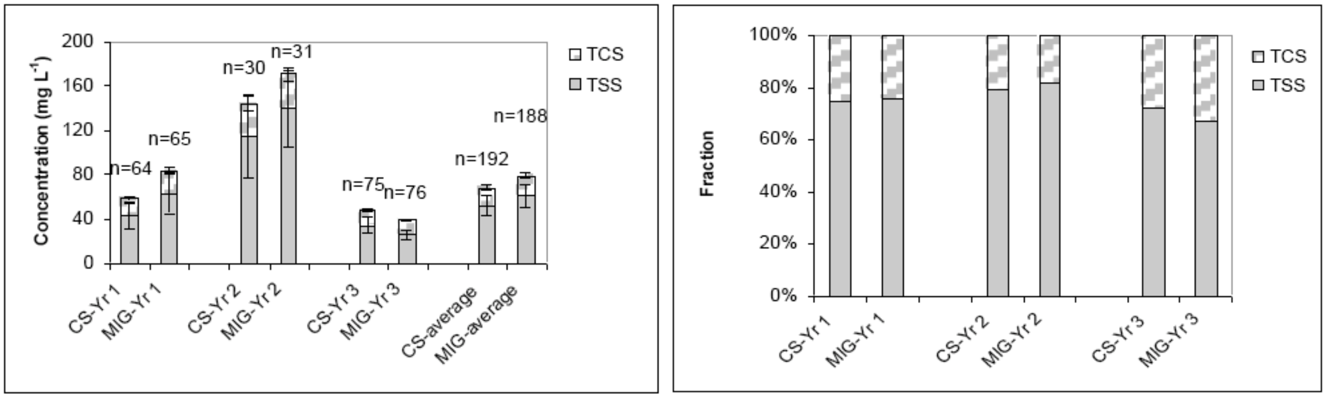
*Values within columns followed by different letters are significantly different ($P < 0.01$).

200m^3 ha^{-1}). Rainfall intensity affects surface runoff generation as well as concentrations of nutrients in runoff. Infiltration excess runoff requires sufficient rainfall intensity and duration for soil infiltration capacity to be overwhelmed, whereas saturation excess runoff may occur at extremely low concentrations [17]. Sediment loss from a continuously stocked sward maintained at a height of 5 cm was nearly twice that from a rotationally stocked treatment with a 5-cm post-graze sward height [37] because of greater average cover for rotational than continuous stocking.

Udawatta *et al*. [38] investigated N losses in runoff from three adjacent agricultural watersheds for a 7 year period. They showed that 8 runoff events accounted for a greater proportion of TN and NO_3/NO_2-N loss than all the smaller rain events. The result of their study showed the same pattern as our results of TN, NO_3/NO_2-N and NH_4-N loss in 3 years study. The rate of N loss in surface runoff from grazed swards is relatively low, and may be even less than that received *via* deposition [39]. Runoff losses of N from summer-grazed pastures in Ohio were less than 1.0 kg ha^{-1} y^{-1} [40]. Runoff from pasture receiving 224 kg N ha^{-1}y^{-1} with rotationally grazed beef cattle also showed low N losses, with nitrate concentrations well below 10 mg L^{-1} [41]. Edwards *et al*. [42] found that application of manure in simulated dung pats to 15 m^2 pasture plots at rates up to 5.6 kg per plot had negligible effect on the nutrient content of overland flow.

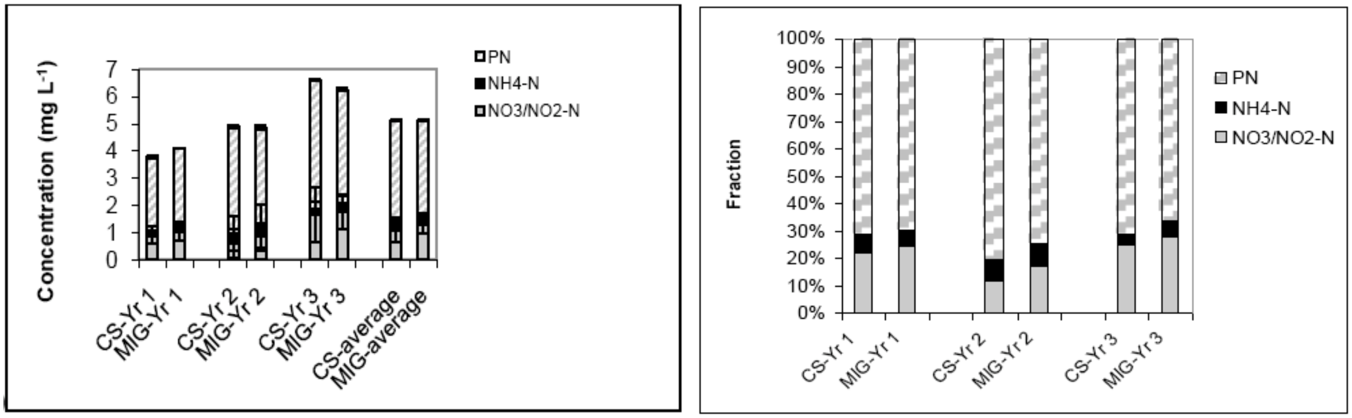
Regression analyses of surface runoff events by Owens and Shipitalo [43] indicated a stronger relationship for total dissolved reactive P (TDRP) transport vs. size of runoff event than for TDRP vs. total P concentration. They found that surface transport of TDRP was more dependent on the amount of runoff than concentration of TDRP, and that TDRP concentration was not dependent on the amount of runoff. Haygarth and Jarvis [44] also reported greater nutrient concentrations and transportation from infrequent larger runoff events than from frequent small rain events.

The relationship between runoff volume and nutrient losses are shown in linear regression analysis for CS and MIG treatments (Figures **2** and **3**). Runoff volume and P (TP and SRP) losses were significant for both grazing treatments (R^2 = 0.58-0.78, $p < 0.001$) with a higher positive r^2 compared to the regression of N (R^2 = 0.20-0.57, $p < 0.001$). The relationship between runoff volume and NO_3/NO_2-N was the weakest in both CS and MIG treatments. In general, rainfall and seasonal effects are critical for runoff volume. Thus, heavy rainfall produces an initial high rate of discharge that is a significant amount in the proportion of the total discharge. These runoff events removed several magnitudes more TN and TP than the small rain events. Edwards and Owens [45] showed that two or three runoff events each year were responsible for substantial annual soil losses. The results of this study also show that years 1 and 3, which generated 15 % more volume compared to year 2, account for a high proportion of total nutrients losses. The more frequently occurring small runoff events (≤ 200 m^3 ha^{-1} total runoff) in MIG account for a larger portion (88.6% of TN and 87.3% of TP in the total) of the nutrient losses compared to the losses from the two infrequent large events of more than 500 m^3 ha^{-1}. In CS, the frequent small events accounted for 54.0% of TN and 60.2% of TP in the total losses compared to the losses from the five infrequent large events. More runoff occurred (P <



(**A**) (**B**)

Figure 2: (**A**) Mean comparison of total suspended solid (TSS) and total combustible solid (TCS) from runoff in continuous stocking (CS) and management intensive grazing (MIG) plots, UL-Lafayette Cade Farm, 2001-2004. Error bar indicates the standard error of means. (**B**) The fraction of TCS and TSS in CS and MIG treatment by year.



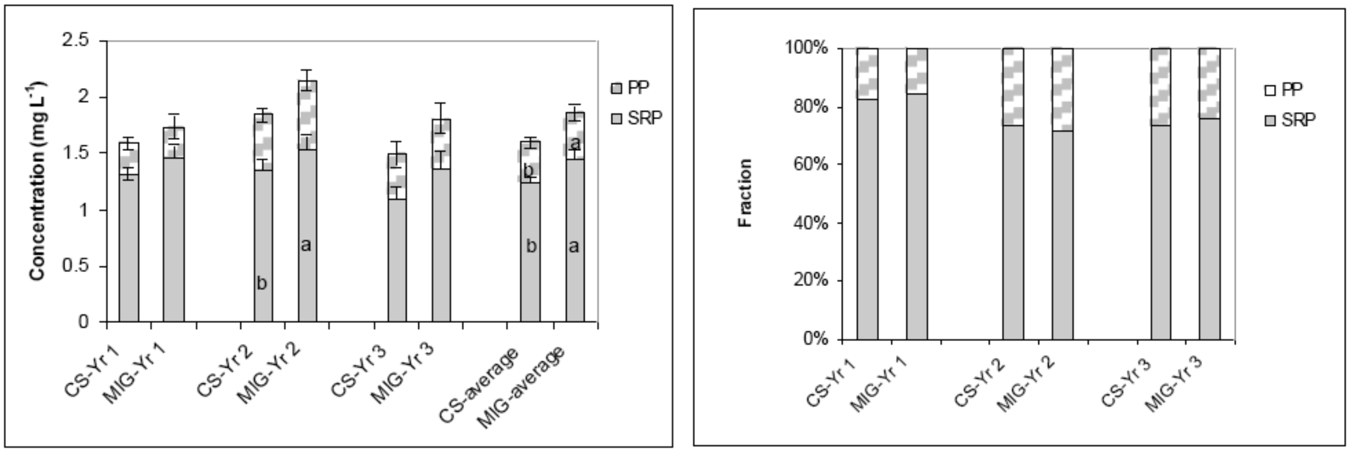
(**A**) (**B**)

Figure 3: (**A**) Mean comparison of TN, NO_3/NO_2-N, NH_4-N, and PN from runoff in continuous stocking (CS) and management intensive grazing (MIG) plots, UL-Lafayette Cade Farm, 2001-2004. Error bar indicates the standard error of means. (**B**) The fraction of TN, NO_3/NO_2-N, NH_4-N, and PN in CS and MIG treatment by year.

0.05) from the CS treatment with more infrequent large (≥ 500 m^3 ha^{-1} total runoff) events than from the MIG plots. We attribute this to the influence of the grazing management effects with more ground cover in the MIG treatment. Sanjari *et al*. [46] in Australia noted that in ‘Time-controlled’ grazing the sediment loss was reduced significantly under T-C grazing when compared with continuous grazing irrespective of the size of runoff events. The CS plots tended to have shorter forage height overall whereas in the MIG plots several of the 20 paddocks had variable forage heights that were more restrictive of runoff.

Although infrequent larger events remove proportionately larger quantities of N and P from pasturelands, more frequent small rain events cumulatively remove larger quantities over an extended period of time. Kleinman *et al*. [47] observed that runoff hydrology was greatly influenced by interactions between seasonal moisture conditions, soil/landscape location and rainfall intensity. Factors that influence the amount of P desorbed and consequently the P concentration in the runoff include the contact time between runoff water and P source and the runoff to P source ratio [16].

The predominance of SRP in runoff indicates that erosive losses of P were small and is in agreement with other studies and reviews which have concluded that grassland is a significant source of SRP rather than PP [17, 48, 49]. Regression analyses of surface runoff events indicated a stronger relationship for TDRP transport vs. size of runoff event than for TDRP transport vs. TDRP concentration (Figure **3**). Even with



(**A**) (**B**)

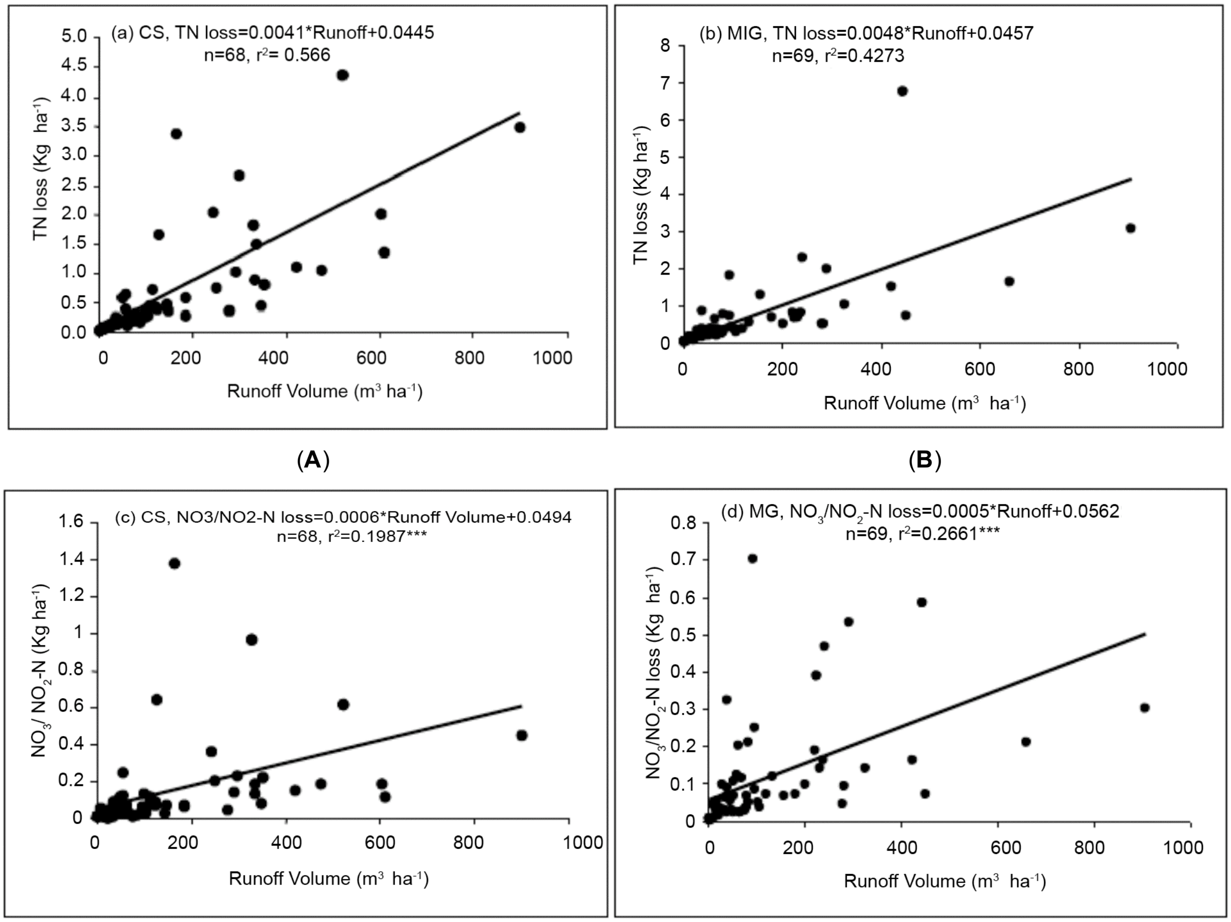
Figure 4: (**A**) Mean comparison of SRP and PP as TP from runoff in continuous stocking (CS) and management intensive grazing (MIG) plots, UL-Lafayette Cade Farm, 2001-2004. Error bar indicates the standard error of means. Values with different letters are significantly different at 0.05 probability level based on student t-test. (**B**) The fraction of SRP and PP as TP in CS and MIG treatment by year.

the stronger relationship of TDRP *vs*. size of runoff event, there was still some scatter of plotted data and explanation was difficult. Most of the runoff was in the top five TDRP transport events (>0.5 kg ha^{-1}). These results indicate that surface transport of TDRP was more dependent on the amount of runoff than concentration of TDRP, and that TDRP concentration was not dependent on the amount of runoff. Thus, to reduce surface transport of TDRP, practices that reduce surface runoff may be more important than practices that reduce TDRP concentration in runoff. Certainly reducing both runoff and concentration would have the greatest impact.

While the concentration of P in runoff is related to soil P, the potential for P loss from a site will be dependent on runoff potential. Thus, a comprehensive approach that integrates soil P levels with the variability in runoff volume and erosion, resulting from climatic, topographic, and agronomic factors, will be needed for reliable yet flexible recommendations of fertilizer and manure P management [50].

3.3. Flow-Weight Concentration

The average concentration of the total suspended solids (TSS) and total combustible solids (TCS) were 47.0 mg L^{-1} (ppm) in CS and 54.7 mg L^{-1} (ppm) in MIG, and 16.1 mg L^{-1} (ppm) in CS and 19.0 mg L^{-1} (ppm) in MIG treatment, respectively. However, there was no significant difference (P >0.10) between CS and MIG in TSS and TCS in the yearly comparison and the 3-year average (Figure **4A**.). During year 3, TCS as a fraction of TSS increased 17% in MIG compared to year 1 (Figure **4B**). On other hand, the CS treatment only showed a 3.7% increase in the fraction of suspended solids from year 1 to year 3. As a percent of TSS, TCS ranged from 22 to 49% over the three years with the mean 32.1% and 31.4% for CS and MIG, respectively. Both an increase in plant productivity as well as a greater number of animals with increased excreta contributed to a slight increase OM in the runoff from the MIG treatment.



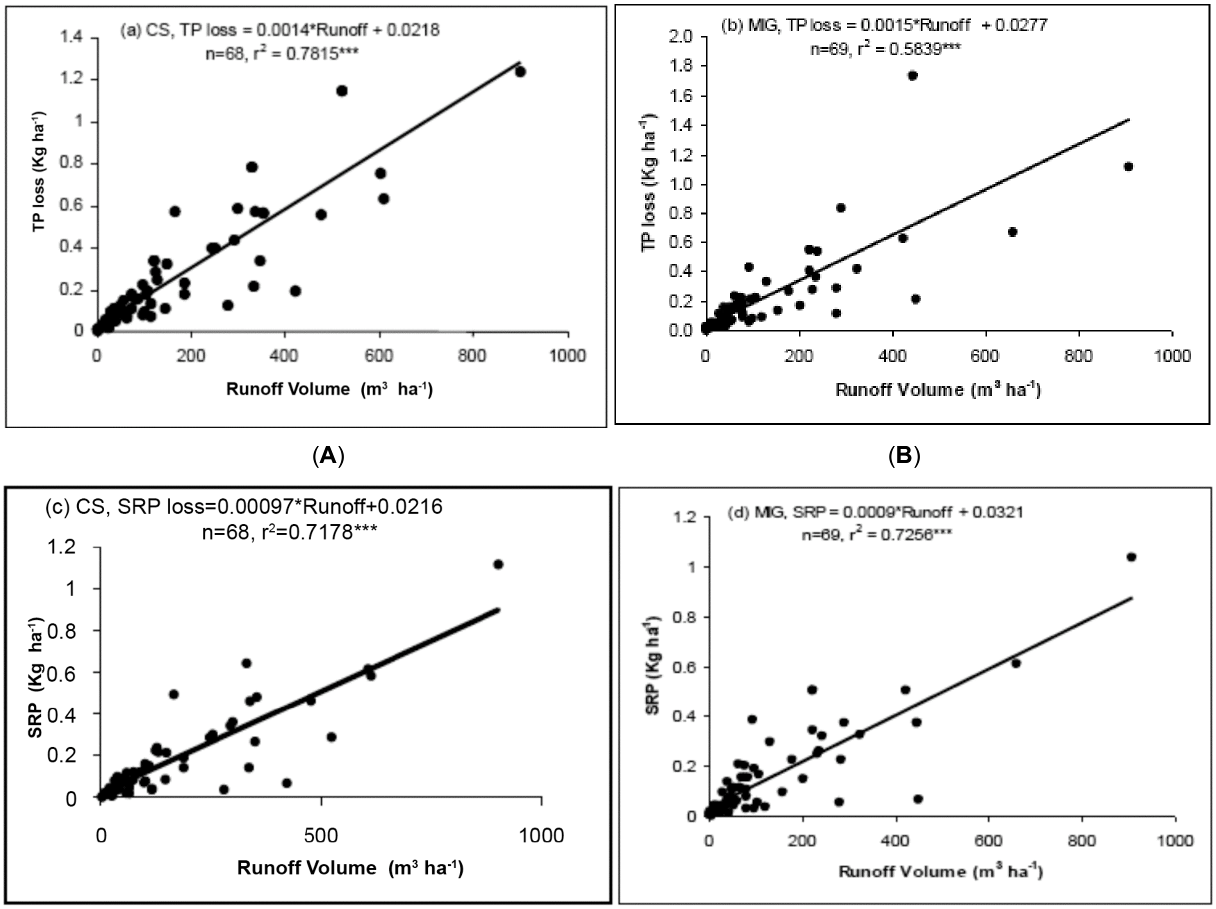
(**A**) (**B**)

(**C**) (**D**)

Figure 5: Plots of N transport *vs*. size of runoff event from plots 2001-2004: (**A**) TN from continuous grazing (CS); (**B**) TN from MIG; (**C**) NO_3 from CS; (**D**) NO_3 from MIG.

Nitrogen concentrations in surface runoff vary significantly in time and space [51], with N concentration and the volume of water determining the load of N exported. Theoretically, variations in N concentrations in surface runoff (particularly with time) reflect a change in the magnitude, form or mobility of one or more N sources in the pasture system. No significant differences ($P > 0.05$) occurred between treatments in any of the nitrogen components-- TN, NO_3/NO_2-N, NH_4-N, and PN (Figure **5A**). The 3-year average values of TN, NO_3/NO_2-N, NH_4-N, and particulate N (PN) were 5.1, 1.1, 0.28, and 3.74 mg L^{-1} (ppm) in CS, and 5.1, 1.3, 0.3, and 3.5 mg L^{-1} (ppm) in MIG. The fraction of NO_3/NO_2-N and TN ranged from 12.1 to 24.9% during the study period (Figure **5B**). McDowell, *et al*. [52] observed that NO_3-N concentrations in overland flow from pasture treatments with applied cow dung were generally unaffected by the dung deposition, indicating that NO_3-N was being retained and perhaps used by the limited pasture growth during their study.

The concentration of P as SRP was greater ($P < 0.05$) from MIG than CS in year 2 and the three-year average (1.5 vs. 1.3 and 1.4 vs. 1.2 mg L^{-1} [ppm]), respectively (Figure **6A**). Phosphorus in runoff is primarily in dissolved reactive form with the concentration corresponding with soil test P levels. Site hydrology, not chemistry, is primarily responsible for variations in mass N and P losses with landscape position. Although, there is good evidence that rain leaches P from plant biomass, Sharpley [53] showed that subsequent interaction of rainfall/runoff that contains the biomass P with the soil surface means that it is ultimately the soil that controls runoff P concentration. Therefore, the measured P in the runoff from these pastures was from the soil and the accumulated cattle excreta. The SRP in this study accounted for 70-83% of the total P in runoff (Figure **6B**). Dougherty, *et al*. [17] attributed the concentration of P in runoff to being a function of the equilibrium between the solid and solution phases. Three factors determine this equilibrium, namely, rate of release of P from soil to solution, time of contact, and soil P concentration.



(**A**) (**B**)

(**C**) (**D**)

Figure 6: Plots of total phosphorus (TP) and soluble reactive phosphorous (SRP) transport vs. size of runoff event from grazing plots, 2001-2004: (**A**) TP from continuous grazing (CS); (**B**) TP from MIG; (**C**) SRP from CS; (**D**) SRP from MIG.

The transfer of P is not only a function of the quantity of soil mobilized, but also of the concentration of P in the material transported [54]. Kuykendall *et al*. [36] reported that measurements of total P concentrations in runoff indicated that SRP accounted for 75 and 64% of total P in two years from broiler litter application. The phosphorus in runoff is predominately DP (avg. 96% of total P), which is the typical result for P in runoff from pastures [19, 55]. The mean flow-weighted concentration of DRP (dissolved reactive P) during the baseline period in the Georgia study was 0.4 mg P L^{-1} [36]. They assumed the DRP was likely to have been derived from the dung deposited by grazing cattle since the soil only had a relatively small initial amount of available P (13 mg P kg^{-1} by Mehlich 1). Swain *et al*. [56] noted that pasture type significantly affected environmental factors and nutrient runoff; average P runoff from improved summer pastures (1.71 kg P·ha^{-1}·y^{-1}) was much greater than from semi-native winter pastures (0.25 kg P·ha^{-1}·y^{-1}), most likely because of past P fertilizer use in improved pastures.

A value of 1 mg PL^{-1} is the value that has been tentatively proposed as the maximum desirable concentration in surface runoff from agricultural fields [57]. In intensively managed pasture systems, the size of the various pools of P and the turnover rates of these can be large. Typically, only a small fraction of each pool is available for mobilization. For example, only 1 to 5% of total soil P is water soluble [55, 58]. Fecal P can contribute to the P in runoff [59, 60]; however the contribution of fecal P to runoff P is small. Haan *et al*. [37] found the mean total-P in runoff was 34% greater with continuous stocking to maintain a 5-cm height than with rotational stocking leaving a 5-cm post-graze stubble, and 3.7 times greater than rotational stocking leaving a 10-cm post-graze stubble

Incidental losses from dung are not as large and the effect of time since grazing and dung deposition is relatively weak compared with that for fertilizer [60, 61] because of the relatively small amounts of dung deposited under grazing conditions, compared with fertilizer, and the relatively small surface area of dung exposed [62]. Monaghan *et al*. [63] measured the mean load of P lost in overland flow in a dairy grazing study on a soil with a mean soil Olsen P concentration of 30 mg kg^{-1}. The P lost ranged from 0.3 kg ha^{-1} to 0.8 kg ha^{-1}. Phosphorus losses from dung were 25-36% of the total P lost with 51-64% of the total coming from the soil.

3.4. Forage and Beef Production

Total forage production (Table **2**) on the MIG plots reflected a 15% advantage over the CS system (19,796 Kg ha^{-1} for MIG, and 16,964 Kg ha^{-1} for CS). Sollenberger, *et al*. [64] concluded from 23 different studies that rotational stocking increases forage quantity-related responses relative to continuous stocking, and the average advantage for rotational stocking is about 30%.

The total animal grazing days available for the period June 2001-March 2004 showed an annual average of 1573 d ha^{-1} for MIG and 1184 d ha^{-1} for CS.

Table 2: Forage and Beef Production: Dry Matter (DM), Crude Protein (CP), Grazing Days (GD), and Beef Weight Gain as Measured Monthly from Continuous Stocking (CS) and Management Intensive Grazing (MIG) Plots, UL-Lafayette Cade Farm, 2001-2004

	Forage Production			
	Total DM	**CP**	**Animal Grazing**	**Beef Gain**
	Kg ha^{-1} yr^{-1}	**%**	**day^{-1} ha^{-1} yr^{-1}**	**Kg^{-1} ha^{-1} yr^{-1}**
CS	19691^{b*}	11.48	1431	845^{d}
	14790^{d}	14.32	1504	1774^{b}
	16412^{bc}	13.89	1309	1316^{c}
3-yr mean	16964	13.19	1415	1309
MIG	23506^{a}	12.37	1555	1121^{c}
	17063^{bc}	14.89	1660	2172^{a}
	18818^{b}	15.29	1641	1648^{b}
3-yr mean	19796	14.12	1619	1637

*Values within columns followed by different letters are significantly different ($P < 0.05$).

Stocking density on the MIG plots ranged from 50 to 130 AU ha^{-1} d^{-1} which was two to seven animals on each 0.04 ha paddock daily. With more forage dry matter available, total beef production increased with the MIG system (3-year total beef gain: MIG – 1267 Kg ha^{-1} *vs*. CS - 1072 Kg ha^{-1}; annual average: MIG – 422 Kg ha^{-1} *vs*. CS – 330 Kg ha^{-1}). In a review of grazing management for rangelands, no advantage is evident for rotational stocking [21], however, Sollenberger, *et al*. [64] noted that the exception for pastureland appears to be greater for an advantage in gain per ha for rotational stocking of pastureland than rangeland. However, Earl and Jones [65], showed that vegetation cover was greater, on average, using rotational than continuous stocking, indicating that a change in stocking method could have long-term implications for water quality.

This increased beef production per hectare increases the land efficiency without sacrificing the environmental quality of soil and water. Although, MIG, as a management system supports an increase in land productivity with more available forage and more total animal weight gain per unit of land, individual animal performance is reduced. Pavlů *et al*. [66] also found the seasonal live-weight output per hectare under intensive grazing was approximately 1.5 times higher than a more extensive treatment.

The forage mass for Midwestern dairy MIG pastures was greater than the control or unmanaged pastures every week of the 24-wk grazing season, averaging 1763 lb/acre for ready-to-graze MIG paddocks vs. 850 lb/acre for the control [4]. These ready-to-graze MIG paddocks had significantly greater quality than CON pastures at equivalent levels of forage biomass. The MIG system allows sufficient plant growth recovery before regrazing and prevents overgrazing, loss of stand and soil exposure. Oates *et al*. [67] noted that potential utilizable forage and relative forage quality were significantly greater under management-intensive rotational grazing when compared to continuous grazing and haymaking. Their results point to managed grazing as a viable alternative to continuous grazing and haymaking in terms of both forage production and quality.

Total nutrient budgets for pasture conditions seldom show excessive nutrient applications from manure distributed by grazing animals. Cattle transform nutrients from less available forms in vegetation to more labile forms in dung and urine suggesting a possible mechanism whereby they might increase nutrient runoff. Gilker [68] found no indication that MIG dairy pastures were a source of nutrient pollution to two streams running through grazed watersheds in Maryland. The MIG protected the watershed from erosion and most nutrient runoff and produced relatively low levels of nitrate in groundwater.

Leaching of nutrients from these waste products during heavy rains when livestock are more concentrated could increase nutrient runoff. However, in this study, despite the potential for increased runoff due to increased cattle concentration our results show that 42% less runoff occurred (635mm for MIG vs 785 mm for CS, annually) with MIG because of the better forage management. The intensive managed pasture system always had 100% ground cover to intercept raindrops and therefore reduce the kinetic energy whereas the CS system tended to experience areas of spot grazing with some bare ground.

3.5. Seasonal Nutrient Losses

We explored the relationship between CS and MIG with season by looking at the difference between the fall/winter months and the spring/summer months difference (fall/winter difference of CS minus MIG minus spring/summer difference). For these comparisons we tested the nondirectional hypothesis of unequal mean differences by season of year (Table **3**). There was no significant difference in TSS or TCS between grazing method (P values 0.38-0.85) although more TSS in runoff was observed in MIG during fall/winter as indicated by negative value (-1042.2). There was a significant seasonal difference in flow-weighted loads between the fall/winter mean difference (CS - MIG) and the spring/summer mean difference (CS - MIG) for total N ($p = 0.005$) and for NO_3/NO_2–N flow- weighted load ($p = 0.048$). Greater losses of N occurred during the winter months. More total N occurred in fall/winter runoff from CS than MIG as observed by high positive value of 148 (Table **3**). There was a significant difference between the fall/winter mean difference (CS - MIG) and the spring/summer mean difference (CS - MIG) for total N total load (two-sided $p = 0.005$). Sixteen times the total N was observed in fall/winter runoff (148 vs. 9 g ha^{-1}) in contrast to the amount of N lost in the spring/summer between CS and MIG. In the CS treatment the ryegrass during the winter allowed more N loss than in the MIG paddocks where the forage mass accumulation produced less total N in the runoff (Table **3**).

Table 3: Seasonal Analysis of Water Quality Mean Differences Between Continuous Stocking (CS) and Management Intensive Grazing (MIG) Plots, UL-Lafayette Cade Farm, 2001-2004. Standard Error Indicates that Standard Error of the Mean Values from Mean Difference between CS and MIG Treatment in Fall/Winter and Spring/Summer

	n	Fall/Winter	N	Spring/Summer	Standard Error	p-value
		g ha^{-1}		g ha^{-1}		
TSS	28	-1042.2	32	28.92	1199.8	0.376
TCS	28	10.77	32	-41.29	274.21	0.850
TN	28	147.98	32	8.65	48.1	0.005
NH_4-N	28	7.53	32	-2.01	6.06	0.121
NO_3/NO_2-N	28	23.36	32	-13.85	18.42	0.048
TP	28	22.27	32	14.41	27.3	0.774
SRP	28	16.19	32	5.76	16.28	0.524
		Liter		Liter		
Flow	28	21323.14	32	16774.38	13591	0.739

P-value indicates two side values from the results of fall/winter and spring/summer.

To investigate the dependence of the loads on the time between rainfall events the total loads were regressed on the gap (number of days) between the rainfall events. None of these regressions were significant ($P > 0.10$). Grazing method had no effect ($P > 0.10$) on mass of nutrients lost from each pasture system (Table **1**). The year 2 average loss, however, was greater ($P < 0.01$) than years1 or 3 for TSS, Total N, and NH_4^+. Total N in surface runoff varied based on the amount and the duration of the rainfall event and on the volume of runoff. This total N from the MIG plots represents an 11% reduction in the amount of N leaving the MIG plots. This trend is an improvement, but because of extreme variation among the samples, no statistical significant difference ($P > 0.10$) between treatments in amount of total N, NO_2/NO_3, or NH_4 content of runoff water was evident. A spike in NO_3-N runoff occurred in November of each year because of the nitrogen fertilizer applications to the ryegrass and frequent small rainfall events. An even greater spike occurred in NH_4-N in November of 2002, as the rainfall event of 0.73 cm hr^{-1} occurred immediately following the N fertilizer application and apparently some of the dissolved fertilizer N was captured in the runoff.

Rainfall intensity affects surface runoff generation as well as concentrations of nutrients in the runoff [17]. The infiltration excess that affects runoff requires sufficient rainfall intensity and duration for soil infiltration capacity to be overwhelmed, whereas saturation excess runoff may occur at extremely low rainfall intensities [18]. Surface runoff of N is generally not seen as a dominant pathway for N transport [47].

Dubeux *et al*. [69] compared dung distribution of heifers under two rotational stocking strategies (7-d and 1-d of grazing period) with continuous stocking on Pensacola bahiagrass (*Paspalum notatum* Flügge) pastures. Rotational stocking with a 1-d grazing period promoted a more uniform dung distribution compared to rotational stocking with 7-d grazing periods and continuous stocking, While manure from grazing cattle generally has a lower concentration of P than other livestock manures, low soil sorption and high percentage of water extractable P require that P be well managed in cattle grazing systems to prevent environmental contamination. Consideration of runoff N is necessary to the development of nutrient management strategies, it is important to note that surface runoff is generally not seen as a dominant pathway for N transport [47]. Because the MIG system protected the watershed from erosion, reduced total runoff volume and produced relatively low levels of nutrients in the runoff, this grazing management system can be considered as a potential environmental Best Management Practice.

4. SUMMARY AND CONCLUSIONS

The high stock density of Management Intensive Grazing (MIG) produces more uniform manure distribution than lower stock densities. Shorter grazing periods in smaller paddocks are effective for increasing stock density and are an effective BMP over continuous grazing. In this study, more forage production allowed more grazing days with an increase in total beef production per ha with the MIG system without adversely affecting the water quality. Animal and plant management data support MIG as a better management system for plants, animals, soil, and water. Runoff from the MIG treatment was reduced by 21% over the CS. The average runoff from MIG was 34% (485 mm ha^{-1}) of the recorded rainfall and 42% (685 mm ha^{-1}) from CS. Although no significant difference in sediment runoff between treatments was observed, less TSS in the surface runoff from both treatments was evident in Y3 than in the previous two years. During this three-year study, no significant treatment differences were found in the water quality parameters of nutrient runoff or sediments. This improved productivity of pastures, animals, and of general environmental conditions supports the practices of MIG as a BMP.

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