Chapter 4. Results and Discussion

Forage and manure treatments and interactions discussed in this chapter are abbreviated as described in Table 4-1. The designator O represents forage treatments with predominantly orchardgrass stands; the designator B represents broadleaf treatments. Manure treatments serving as proxies for stocking densities are referred to by the designator C for no manure application (control), H for high stocking density, and L for low stocking density. Interactions between treatments are designated as summarized in Table 4-1.

Table 4-1: Manure x Forage Interaction Abbreviations

Treatments and Interactions	Designator
Broadleaf Forage	B
Orchardgrass Forage	O
Control Manure	C
Low Manure	L
High Manure	H
Control x Broadleaf forage	CB
Control x Orchardgrass forage	CO
High x Broadleaf forage	HB
High x Orchardgrass forage	HO
Low x Broadleaf forage	LB
Low x Orchardgrass forage	LO

Runoff release plots were simulated during the establishment year for the forages seeded. Forage stands thickened and developed as the season progressed affecting the ability of plants to uptake P and to hold sediment bound P in place. Natural rainfall for the season was higher than average and followed a four-year drought period (Figure 4-1). The lack of rainfall in previous seasons contributed to predominantly dry soil conditions early in the season.

4.1 Rainfall Data and Simulations

The simulation season was an unusually wet season; rainfall amounts were in excess of average seasonal conditions and were marked by rare storms producing high intensity rainfall events (Figure 4-1). This wet season followed a four-year drought period in the area that had excessively depleted soil moisture. Natural rainfall amounts in excess of average storms and conditions on these dry soils led to saturated soils conditions during some rainfall simulation series that would quickly change to dry, surface-sealed conditions as soils dried due to hot, sunny conditions

Rains in early May resulted in wet soils for most of the early spring season. The wet conditions stunted the growth of the newly planted alfalfa stands and allowed dormant seeds in the soil to thrive and smother out the alfalfa seedlings. The intended alfalfa stands resulted in a mixed broadleaf stand of red clover, buckhorn plantain, and alfalfa.

Large storms in early June leading up to and through part of rainfall simulation series 1 saturated soils and made conditions perfect for fast runoff generation and large runoff amounts. Natural rainfall events between series were unable to be monitored for runoff volume and sampled to determine potential losses between simulation series. As a result, all time interactions presented here are not representative of continuous sampling, but rather point in time measurements.

Rainfall simulations ranged from 0.537 to 2.12 hr for the entire season. The variability in this range is due to the antecedent moisture conditions of the site as influenced by the wet season. The average uniformity coefficient for simulated rainfall was 0.941 (Appendix E), indicating consistent coverage of al plots during the simulations.

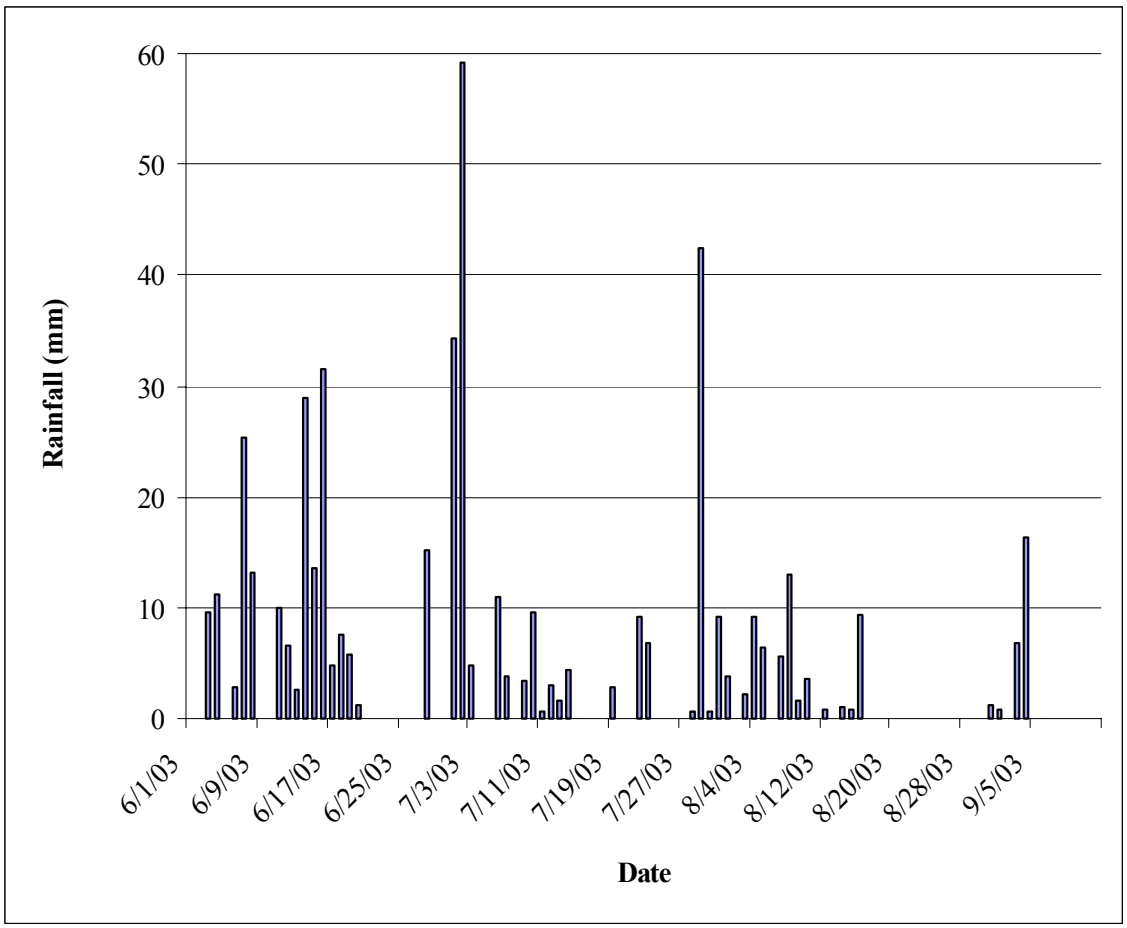

Figure 4-1: Natural Rainfall Amounts during Simulation Season (NWS, 2003)

4.2 Runoff Depth

Runoff depths ranged from 0.30 to 18.93 mm (Appendix D). Variability is due to the natural rainfall events influencing soil saturation conditions. There were no significant ($p > 0.05$) forage or manure treatment effects, but there was a significant forage x manure treatment interaction ($p < 0.05$) (Table 4-2).

Table 4-2: Runoff Volume means and *p* values for forage and manure treatments and forage x manure treatment interactions for all rainfall simulation series conducted summer 2003 at Prices Fork Research Farm, Blacksburg, VA.

Runoff		Depth
Forage Treatment	*p*-value	Depth, mm
B	0.3694	7.40
O		6.65
Manure Treatment		
C	0.4199	7.00
H		6.42
L		7.65
Forage x Manure		
CB	0.0152	9.49
CO		4.52
HB		6.04
HO		6.79
LB		6.66
LO		8.63

* Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
**Pairing of treatment letters indicates a treatment combination.

Analysis of the Fisher's Least Square Difference (LSD) indicated that control orchardgrass plots had significantly lower runoff depth in all simulation series when compared to other treatment plots (Table 4-3). Analysis of the randomized plot layout indicates that the majority of the control orchardgrass plots were concentrated in the northeastern area of the research area. The absence of a significant slope effect ($p > 0.05$) on the plot treatments indicates that slope was not a factor contributing to this particular phenomenon. Runoff data was further analyzed for time interactions within each simulation series.

Table 4-3: Mean separation* between runoff release plot forage and manure treatment combinations for all rainfall simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

Forage x Manure	*p*-value	Depth, mm
CO	0.0152	4.52[a]
HB		6.04[b]
LB		6.66[b]
HO		6.79[b]
LO		8.63[b]
CB		9.49[b]

*Means with same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.
** Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
***Pairing of treatment letters indicates a treatment combination.

There were no significant ($p > 0.05$) forage x time and manure x time interactions, but there was a significant ($p < 0.05$) forage x manure x time interaction.

Table 4-4: Runoff volume means and *p*-values for forage x time, manure x time, and forage x manure x time treatment combinations for rainfall simulations conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

Runoff			Interactions with Time and Treatment			
Depth			Depth, mm			
Time (Run)	1	2	3	4	5	6
Forage x Time			$p = 0.9764$			
B	9.12	7.30	6.83	8.34	8.33	4.46
O	8.99	7.33	5.52	7.25	6.73	4.09
Manure x Time			$p = 0.1334$			
C	9.50	6.08	6.44	8.22	7.65	4.13
H	9.85	6.41	5.06	6.84	6.92	3.42
L	7.82	9.46	7.01	8.33	8.00	5.26
Forage x Manure x Time			$p = 0..6139$			
CB	10.82	10.20	9.16	11.15	10.92	4.68
CO	8.18	1.96	3.73	5.29	4.39	3.59
HB	8.23	5.60	4.81	6.79	7.24	3.58
HO	11.48	7.21	5.31	6.69	6.60	3.27
LB	8.33	6.11	6.51	7.09	6.82	5.11
LO	7.32	12.82	7.52	9.57	9.81	5.40

*Means with same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.
** Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
***Pairing of treatment letters indicates a treatment combination.

Analysis of the Fisher's LSD indicated a significantly lower runoff depth on the CO plots in all series and markedly in Series 2 (Table 4-4). Runoff depth for these plots was significantly different from all other plots in the series. Plot by plot analysis showed that one CO plot in particular exhibited a lower runoff depth than all other CO plots. Statistical analysis indicated no slope effect amongst the CO plots and was rerun with the outlier plot excluded. Results indicated that there was no statistical on levels from any treatment once the outlier plot was excluded (Table 4-5). The anomaly may be due to a failure of the plot setup to catch runoff or to an undetected runoff pathway caused by native fauna. Statistical analysis indicates no significant effect of forage and manure treatment combinations on runoff production with exclusion of this outlier plot. Variability in the plots may mask differences between treatments, but cannot be controlled due to the nature of this experiment.

Table 4-5: Runoff volume means and *p*-values for forage x time, manure x time, and forage x manure x time treatment combinations for rainfall simulations conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA with outlier CO plot excluded.

Runoff			Interactions with Time and Treatment			
Depth			Depth, mm			
Time (Run)	1	2	3	4	5	6
Forage x Time			$p = 0.9764$			
B	9.12	7.30	6.83	8.34	8.33	4.46
O	8.99	7.33	5.52	7.25	6.73	4.09
Manure x Time			$p = 0.1334$			
C	9.50	6.08	6.44	8.22	7.65	4.13
H	9.85	6.41	5.06	6.84	6.92	3.42
L	7.82	9.46	7.01	8.33	8.00	5.26
Forage x Manure x Time			$p = 0.7139$			
CB	10.82	10.20	9.16	11.15	10.92	4.68
CO	8.53	6.21	5.21	6.75	7.15	4.23
HB	8.23	5.60	4.81	6.79	7.24	3.58
HO	11.48	7.21	5.31	6.69	6.60	3.27
LB	8.33	6.11	6.51	7.09	6.82	5.11
LO	7.32	12.82	7.52	9.57	9.81	5.40

*Means with same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.
** Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
***Pairing of treatment letters indicates a treatment combination.

4.3 Soil P Changes

Soil P in this section refers to the Mehlich I extractable P (STP) in the soil (Nelson et al, 1953). Soil tests were conducted the day before the first rainfall simulation and the day after the last simulation concluded. Statistical analysis of the soil P levels before and after simulations were conducted on the runoff release plots indicated no significant difference ($p > 0.05$) for forage, manure, and manure x forage treatment interactions. The low initial soil P at the site and the fertilization of the plots before seeding provided enough soil P for plant needs and establishment. Subsequent additions of manure to the plots were enough to balance soil P needs to plant needs for the growing season. Thus, soil P levels were unaffected by the uptake of P in the growing forage and manure applications.

4.4 Phosphorus mass and concentration losses from runoff release plots for forage and manure treatments and interactions

4.4.1 Manure Treatments

There was no significant ($p > 0.05$) effect on ortho-P concentration or mass losses for manure treatments. A similar analysis of PP and TP concentrations in runoff and mass losses indicated a significant effect ($p < 0.05$) on PP, but no significant effect on TP ($p > 0.05$) for manure treatments (Table 4-6).

Table 4-6: Ortho-P, PP, TP mass losses via runoff from all rainfall simulations conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

		Mass Loss, mg		
Variable	***p*-value**	**C**	**H**	**L**
PP	0.0294	8.35	21.49	8.35
Ortho-P	0.6798	34.44	29.10	39.79
TP	0.2728	56.17	42.12	41.10

***** Ortho-P- Orthophosphorus, PP- Particulate phosphorus, TP- Total phosphorus, C- Control manure treatment, H- High manure treatment, L- Low manure treatment.

Table 4-7: Ortho-P, PP, TP concentration losses via runoff LS Means and *p*-values from all rainfall simulations conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

		Concentration Loss, ppm		
Variable	***p*-value**	**C**	**H**	**L**
PP	<0.0001	0.27	0.53	0.23
Ortho-P	0.9297	1.10	1.04	1.10
TP	0.4191	1.34	1.55	1.29

***** Ortho-P- Orthophosphorus, PP- Particulate phosphorus, TP- Total phosphorus, C- Control manure treatment, H- High manure treatment, L- Low manure treatment.

For ortho-P and TP, the following null hypotheses are accepted for both mass and concentration losses:

$$\mu_C = \mu_H$$

$$\mu_C = \mu_L$$

$$\mu_H = \mu_L.$$

These treatments may not have been significant on ortho-P and TP levels due to masking effects due to overlapping treatments with time (Figure 4-2).

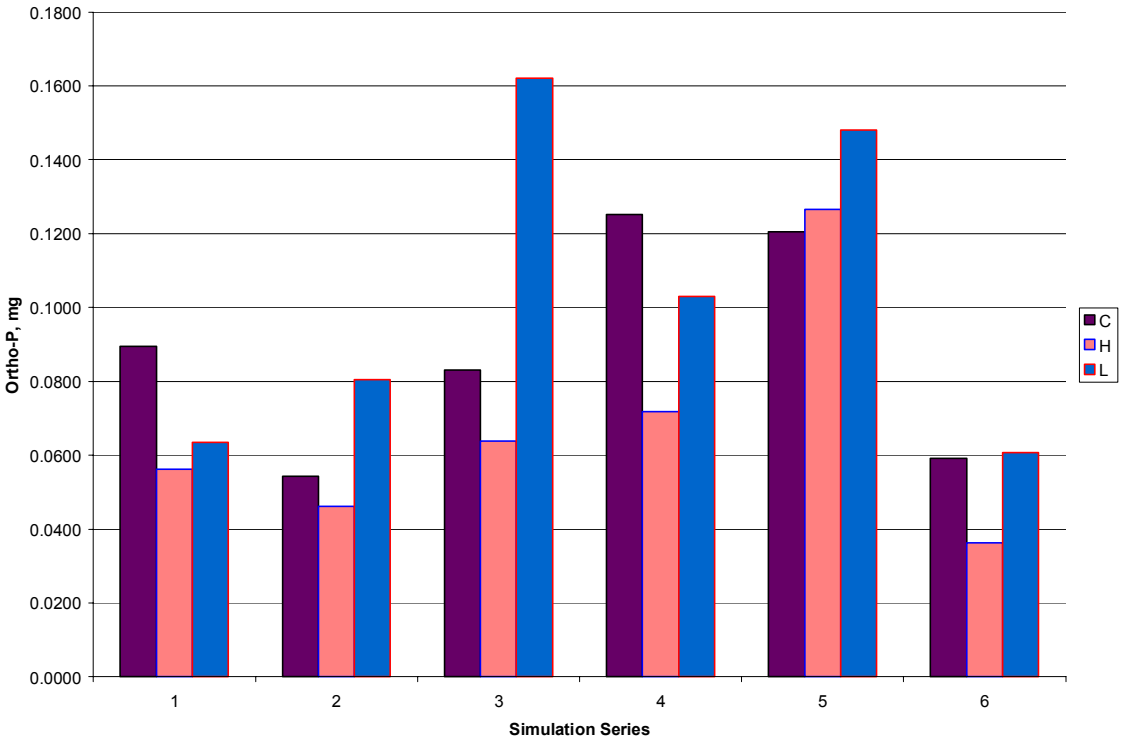

Figure 4-2: Ortho-P mass losses in runoff means for all simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.
* C- Control manure treatment, H- High manure treatment, L- Low manure treatment.

An analysis of the Fisher's LSD on PP LS means indicated that PP concentrations and mass losses were significantly higher ($p < 0.05$) for the high stocking rate manure treatment (Table 4-8 and Table 4-9).

Table 4-8: Fisher's LSD pair-wise comparisons* for PP mass losses via runoff for manure treatments in all rainfall simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

Treatment	PP mass loss, mg
C	8.35[a]
L	8.35[a]
H	21.49[b]

*Means with the same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.
** C- Control manure treatment, H- High manure treatment, L- Low manure treatment.

Table 4-9: Fisher's LSD pair-wise comparisons* for PP concentration losses via runoff for manure treatments in all rainfall simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

Treatment	PP Concentration Loss, mg
L	0.23[a]
C	0.27[a]
H	0.53[b]

*Means with the same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.
** C- Control manure treatment, H- High manure treatment, L- Low manure treatment.

For PP, the following null and alternative hypotheses are accepted for both mass and concentration losses:

$$\mu_C < \mu_H$$

$$\mu_C = \mu_L$$

$$\mu_H > \mu_L.$$

4.4.2 Manure x Time Interaction

There was no significant effect ($p > 0.05$) for the manure x time interaction treatments on ortho-P concentrations and mass losses or on TP mass losses. A significant effect ($p < 0.05$) was detected for manure x time interaction treatments on PP concentration and mass losses and on TP concentration losses. The null hypothesis that $\mu_C = \mu_H = \mu_L$ for ortho-P in all simulation series is accepted.

A further analysis of the Fisher's LSD on PP indicated that masses and concentrations in Series 1 were significantly ($p < 0.05$) higher than for all other simulation series (Table 4-10). High amounts of natural rainfall prior to the simulations resulted in saturated soils. Therefore, the excavation and placement of plot borders and collection pans prior to simulations may be contributing factors to the higher levels in Series 1. Saturated soil conditions led to short times to runoff and higher runoff volumes as the soil could not infiltrate the rainfall from the simulator. This may explain the lack of significant differences observed in ortho-P levels. The water soluble form of P was likely depleted by the time of simulation due to the natural rainfall events before simulation. A high incidence of loose soil due to plot installation likely contributed to higher TSS and sediment levels observed in the runoff and the propensity for PP to be present in the runoff.

Table 4-10: Runoff release plot concentration and mass losses of PP for rainfall simulation series 1 conducted at the Prices Fork Research Farm, Blacksburg, VA.

Interactions with Time and Treatment		
Manure x Time	Mass, mg	Conc, ppm
p-value	<0.0001	<0.0001
C	23.64[a]	0.62[c]
L	30.25[a]	0.80[c]
H	106.55[b]	2.50[d]

*Means with the same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.
** C- Control manure treatment, H- High manure treatment, L- Low manure treatment.

The Fisher's LSD comparison indicated that high stocking rate manure applied plots were significantly higher ($p < 0.05$) for mass and concentration losses than other treatments during all simulations (Figure 4-3). Higher levels of PP losses on the high stocking rate plots is consistent with previous research findings of higher PP losses with high manure application. Therefore, the following null and alternative hypotheses are accepted for series 1:

$$\mu_C < \mu_H$$

$$\mu_C = \mu_L$$

$$\mu_H > \mu_L,$$

and for all series:

$$\mu_C < \mu_{H1}$$

$$\mu_C = \mu_L$$

$$\mu_{H\,1} > \mu_L.$$

For TP losses in concentration, the Fisher's LSD analysis indicated that high stocking rate manure applied plots for series simulation 1 were higher than all other treatments in all simulation series (Table 4-11). This supports the findings for ortho-P and PP in that while mass losses for TP were not significant ($p > 0.05$), the significant effect ($p < 0.05$) in concentration suggests a higher level of PP losses present in the runoff that contributed to a higher overall TP concentration level.

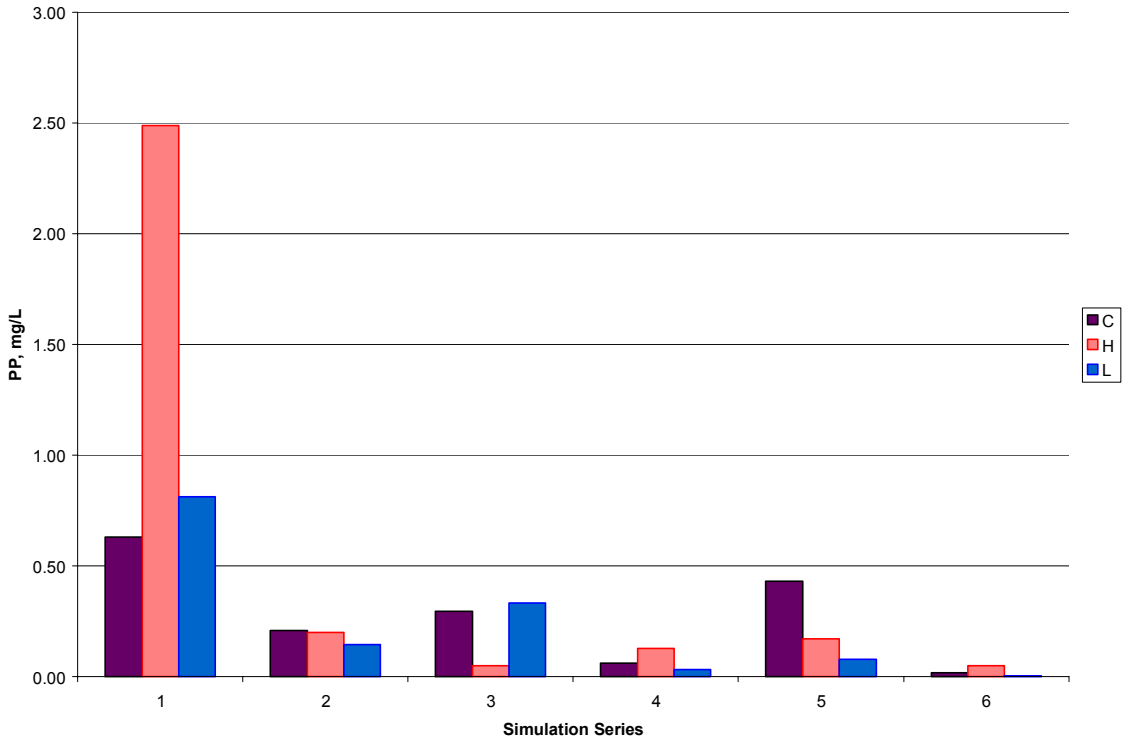

Figure 4-3: PP concentration profile plot for manure x time interaction for all rainfall simulations conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

** C- Control manure treatment, H- High manure treatment, L- Low manure treatment.

Table 4-11: Runoff release plot concentration and mass losses of TP for simulation series 1 conducted at the Prices Fork Research Farm, Blacksburg, VA.

Interactions with Time and Treatment		
Manure x Time	Mass, mg	Conc, ppm
p-value	0.8883	0.0006
H	57.28[a]	3.13[c]
L	64.90[a]	1.41[b]
C	85.30[a]	1.42[b]

*Means with the same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.

** C- Control manure treatment, H- High manure treatment, L- Low manure treatment.

4.4.3 Forage Treatments

There was no significant ($p > 0.05$) effect on ortho-P concentration or mass losses for forage treatments. Analysis of PP and TP concentrations in runoff and mass losses indicated a significant effect on TP ($p < 0.05$), but no significant effect on PP ($p > 0.05$) for forage treatments (Table 4-12, Table 4-13).

Table 4-12: Ortho-P, PP, TP mass losses via runoff means and *p*-values for all rainfall simulations conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

		Mass Loss, mg	
Variable	***p*-value**	**B**	**O**
PP	0.4031	11.17	14.51
Ortho-P	0.5024	37.70	21.19
TP	0.0003	62.46	30.46

*PP- Particulate phosphorus, ortho-P- orthophosphorus, TP- Total phosphorus
** B- Broadleaf treatment, O- Orchardgrass treatment.

Table 4-13: Ortho-P, PP, TP concentration losses via runoff means and *p*-values for all rainfall simulations conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

		Concentration Loss, ppm	
Variable	***p*-value**	**B**	**O**
PP	0.1514	0.30	0.38
Ortho-P	0.1966	1.18	0.98
TP	0.5190	1.44	1.34

*PP- Particulate phosphorus, ortho-P- orthophosphorus, TP- Total phosphorus
** B- Broadleaf treatment, O- Orchardgrass treatment.

For ortho-P and PP, the following null hypotheses are accepted for both mass and concentration losses:

$$\mu_B = \mu_O.$$

An analysis of the Fisher's LSD for PP LS means indicated that TP mass losses were significantly higher ($p < 0.05$) for the broadleaf forage treatment. However, TP concentration losses had no significant effect ($p > 0.05$) (Table 4-14 and Table 4-15).

Table 4-14: Fisher's LSD pair-wise comparisons* for TP mass losses via runoff for manure treatments in all rainfall simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

	TP
Treatment	**Mass Loss, mg**
O	30.46[b]
B	62.46[a]

*Means with the same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.
**PP- Particulate phosphorus, ortho-P- orthophosphorus, TP- Total phosphorus
*** B- Broadleaf treatment, O- Orchardgrass treatment.

Table 4-15: Fisher's LSD pair-wise comparisons* for TP concentration losses via runoff for manure treatments in all rainfall simulation series conducted summer 2003 ate the Prices Fork Research Farm, Blacksburg, VA.

	TP
Treatment	**Concentration Loss, mg**
O	1.34[a]
B	1.44[a]

*Means with the same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.
**PP- Particulate phosphorus, ortho-P- orthophosphorus, TP- Total phosphorus
*** B- Broadleaf treatment, O- Orchardgrass treatment.

For PP, the following alternative hypothesis is accepted for mass losses,

$$\mu_B > \mu_O$$

and the following null hypothesis is accepted for concentration losses.

$$\mu_B = \mu_O.$$

4.4.4 Forage x Time Interaction

There was no significant effect ($p > 0.05$) for ortho-P concentrations and mass losses or on PP concentration and mass losses. A significant effect ($p < 0.05$) was detected on TP concentration losses. The null hypothesis that $\mu_C = \mu_H = \mu_L$ for ortho-P and PP in all simulation series is accepted.

A further analysis of the Fisher's LSD for TP concentrations indicated that concentrations in Series 1 were significantly higher ($p < 0.05$) than simulation series 2, 4 and 6 for the orchardgrass treatment. The high rainfall amounts prior to Series 1 and the early stages of establishment in the forage likely contributed to the higher TP concentrations. The profile plot for forage x time for TP concentrations demonstrates that as the season progressed, orchardgrass TP levels decreased while broadleaf TP levels began to level out at a loss rate higher than orchardgrass (Figure 4-4).

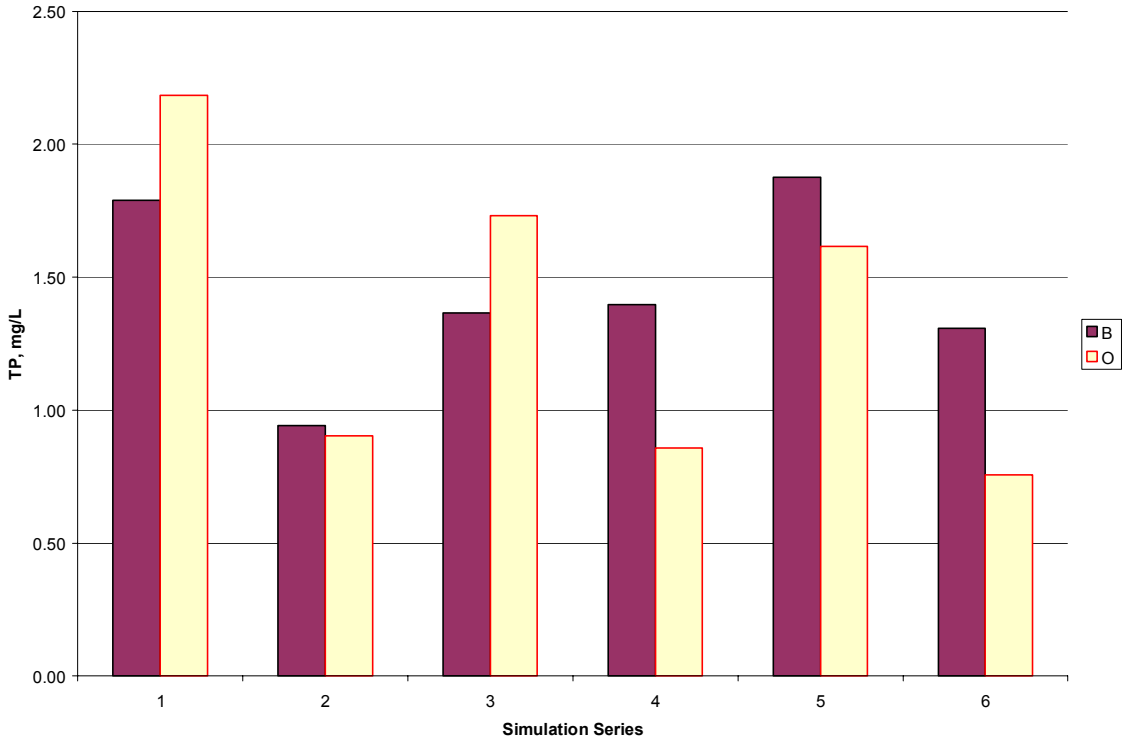

Figure 4-4: Profile plot of forage x time treatment combination for TP for all rainfall simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

*PP- Particulate phosphorus, ortho-P- orthophosphorus, TP- Total phosphorus

** B- Broadleaf treatment, O- Orchardgrass treatment.

The trends of ortho-P and PP over time indicate that the broadleaf treatment released more ortho-P as the season progressed and that PP was decreased in both mass and concentration losses (Figure 4-5 and Figure 4-6). The increasing ortho-P losses from broadleaf treatments over the season indicated that the soil P was increasingly mobilized to plant available forms to support the slower establishment of the species. The mobilization to roots likely contributed to levels in runoff due to a shallow root system indicative of the establishment level of the stand and the wet season in which it developed. Low soil P conditions in which the stand was established may have also led to the development of a proteid root system. The proteiod system has been oserved in white lupine stands growing in low soilP and is used as a means of mobilizing soil P reserves in unavailable inorganic forms to organic forms. The lak of a root development study in this research precludes any definitive conclusion as to the presense of such a root system in this case.

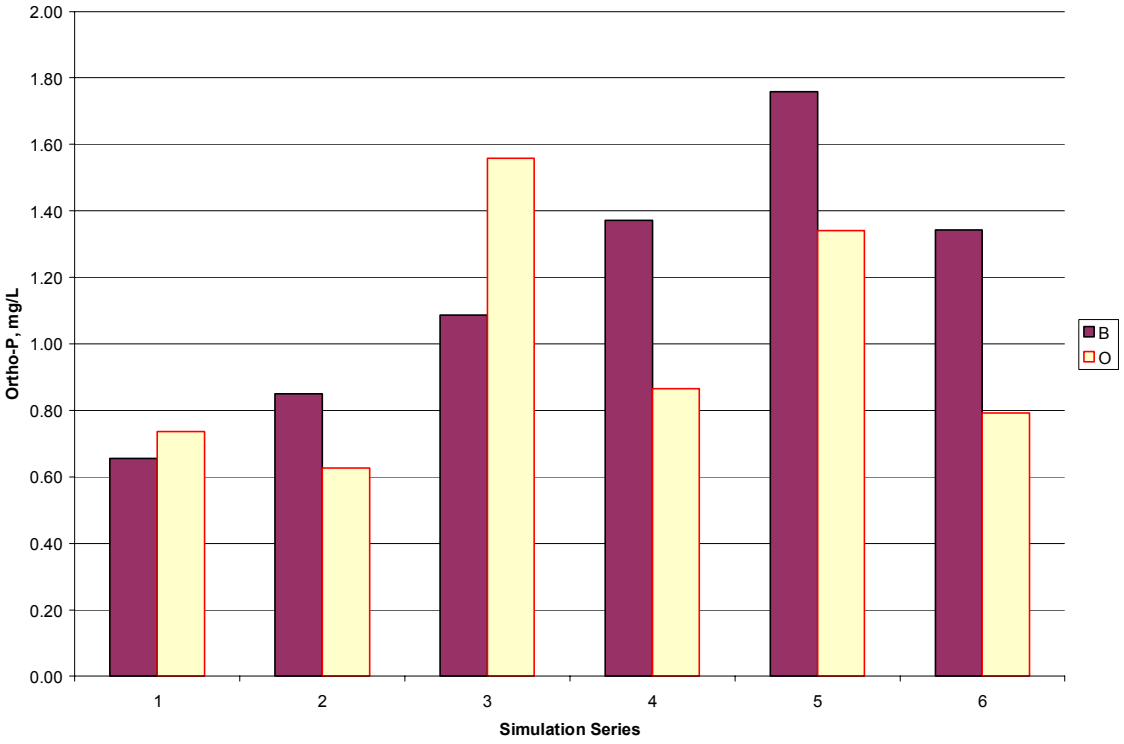

Figure 4-5: Profile plot of forage x time treatment combination for ortho-P for all rainfall simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

*PP- Particulate phosphorus, ortho-P- orthophosphorus, TP- Total phosphorus

** B- Broadleaf treatment, O- Orchardgrass treatment.

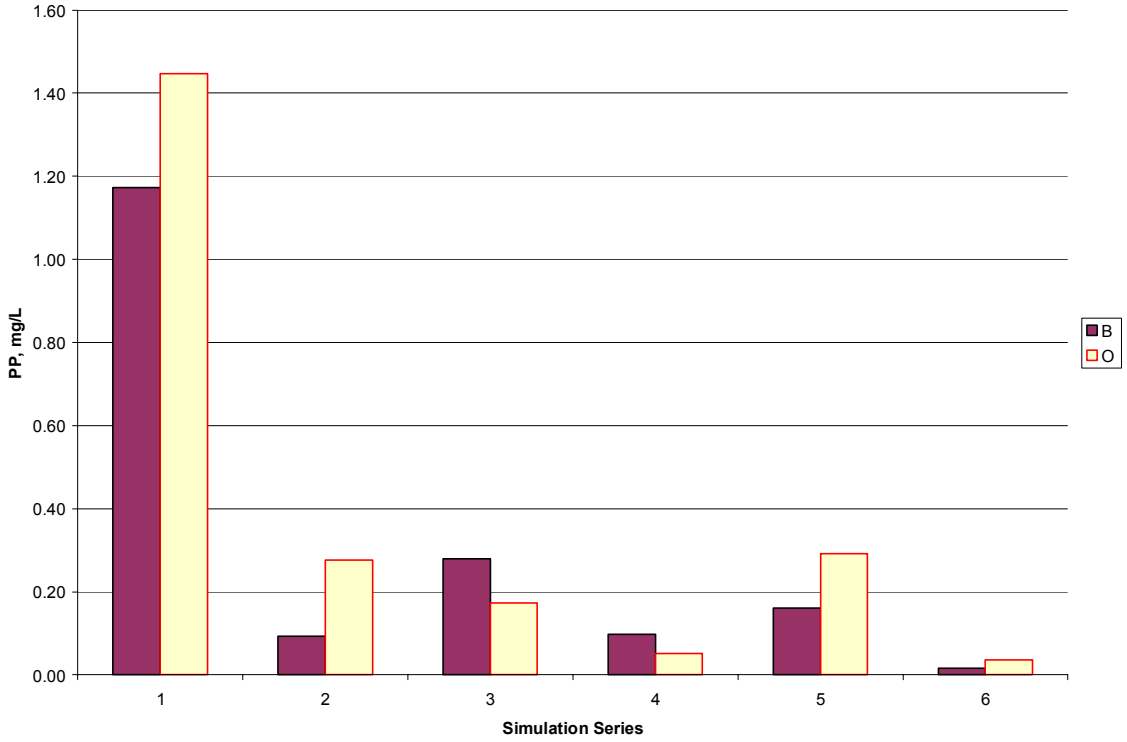

Figure 4-6: Profile plot of forage x time treatment combination for PP for all rainfall simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

*PP- Particulate phosphorus, ortho-P- orthophosphorus, TP- Total phosphorus
** B- Broadleaf treatment, O- Orchardgrass treatment.

The significance of TP is related to the high levels of PP seen in Series 1. The excavation of plots and the low density of the forage during this series led to an elevated level of PP release to runoff. Figure J-8 in Appendix J indicates that the levels of TP dropped significantly and leveled out as the season progressed. Furthermore, the TP levels for broadleaf remained higher as a result of the inability of the broadleaf forage treatment to affect ortho-P levels until the late season re-growth in series 6. While orchardgrass was able to reduce ortho-P levels in each of its re-growth periods, the broadleaf treatment needed the full establishment season to begin reducing ortho-P concentrations.

4.5 Phosphorus mass and concentration losses from runoff release plots for forage and manure treatment combinations and time interactions

4.5.1 Manure x Forage Combinations

There was no significant effect ($p > 0.05$) on ortho-P concentration or mass losses for forage treatments. A similar analysis of PP and TP concentrations in runoff and mass losses indicated no significant effect ($p > 0.05$) on TP and no significant effect on PP ($p > 0.05$) for manure x forage treatments (Table 4-16 and Table 4-17).

Table 4-16: Ortho-P, PP, TP mass losses via runoff means and *p*-values for all rainfall simulations conducted during summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

		Mass Loss (mg)					
Variable	***p*-value**	**CB**	**CO**	**HB**	**HO**	**LB**	**LO**
PP	0.5025	11.17	8.82	16.53	26.46	8.16	8.53
Ortho-P	0.1096	52.52	16.37	31.19	27.00	29.39	50.20
TP	0.1031	77.98	34.36	45.28	38.96	64.12	18.07

* Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
**Pairing of treatment letters indicates a treatment combination.

Table 4-17: Ortho-P, PP, TP concentration losses via runoff means and *p*-values for all rainfall simulations conducted during summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

		Concentration Loss (ppm)					
Variable	***p*-value**	**CB**	**CO**	**HB**	**HO**	**LB**	**LO**
PP	0.5424	0.22	0.32	0.46	0.59	0.23	0.22
Ortho-P	0.1966	1.35	0.85	1.22	0.86	0.96	1.24
TP	0.3310	1.53	1.16	1.65	1.44	1.15	1.42

* Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
**Pairing of treatment letters indicates a treatment combination.

For ortho-P, PP, and TP, the following null hypotheses are accepted for both mass and concentration losses:

$$\mu_{CB} = \mu_{CO} = \mu_{HB} = \mu_{HO} = \mu_{LB} = \mu_{LO}.$$

4.5.2 Manure x Forage x Time Interactions

There was no significant effect ($p > 0.05$) on ortho-P concentrations and mass losses or on TP concentration and mass losses. A significant effect ($p < 0.05$) was detected for PP concentration losses but not for mass losses. The null hypothesis that $\mu_{C} = \mu_{H} = \mu_{L}$ for ortho-P and TP in all simulation series is accepted.

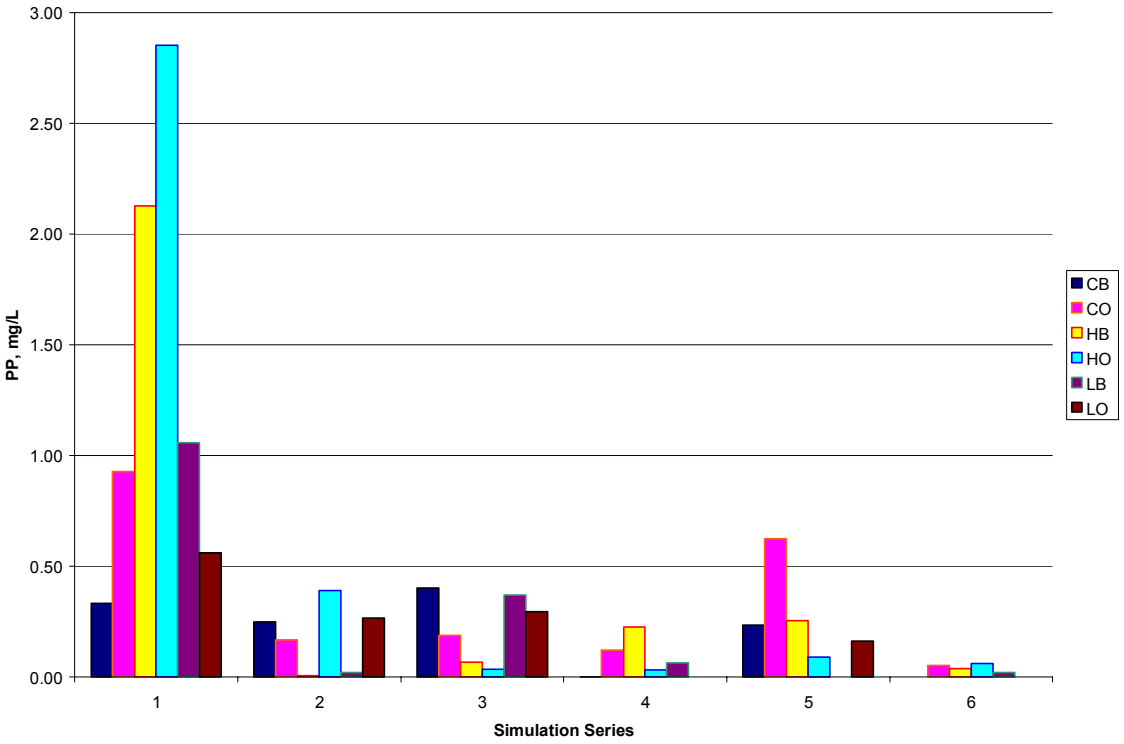

Figure 4-7: Profile plot for PP concentration losses for manure x forage x time treatment combinations for all rainfall simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

* Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
**Pairing of treatment letters indicates a treatment combination.

A further analysis of the Fisher's LSD for PP concentrations indicated that concentrations in Series 1 were significantly higher ($p < 0.05$) than subsequent series for all treatment interactions. The combination of high rainfall amounts prior to Series 1, lack of forage establishment in the early stages, and plot excavation prior to simulation contributed to the higher PP concentrations. The profile plot for manure x forage x time for PP concentrations indicates that PP levels decreased as the season progressed (Figure 4-7).

As demonstrated by the plot, PP concentrations were cyclical throughout the series as forage was cut and allowed to re-grow. The highest PP concentrations occurred during series 1, 3, and 5 when forage was removed and stands were thinned with the exception of the high stocking rate broadleaf interaction. This indicates that, as the forage was established and during re-growth periods, sediment was retained on the plots and a reduction in PP in runoff was achieved.

Some significant differences ($p < 0.05$) occurred between series 3 and 5 for the PP concentration levels (Table 4-18)

Table 4-18: Fisher's LSD comparison for series 3 and 5 rainfall simulations for PP concentrations conducted at the Prices Fork Research Farm, Blacksburg, VA.

Forage x Manure x Time $p = 0.0224$	Series 3	Series 5
HO	0.05^{acd}	0.10^{acd}
HB	0.09^{acd}	0.26^{acd}
CO	0.16^{acd}	0.60^{a}
LO	0.31^{acd}	0.17^{acd}
LB	0.35^{acd}	0.02^{bcd}
CB	0.42^{acd}	0.24^{acd}

*Means with the same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.
** Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
***Pairing of treatment letters indicates a treatment combination.

Control orchardgrass interactions between series 3 and 5 were significantly different (p <0.05). The control plots exhibited a higher PP concentration loss in series 5. In addition, low broadleaf concentrations of PP in series 3 were significantly higher than in series 5. The overlapping nature of the pair-wise comparisons precludes statistical inference on the nature of these differences.

4.6 Statistical contrasts of grazed vs. regrowth periods and broadleaf vs. orchardgrass

Two contrasts were investigated in the statistical analysis of the data. Constituents were contrasted based on a broadleaf vs. orchardgrass comparison and a grazed vs. regrowth simulation series comparison. No significant contrast ($p > 0.05$) on runoff depth was observed for either contrast. There was also no significant contrast ($p > 0.05$) on any water quality constituent tested for the broadleaf vs. orchardgrass contrast (Table 4-19). There was a significant contrast ($p < 0.05$) for the grazed vs. regrowth contrast on PP, TP, and TSS levels. Grazed vs. regrowth contrast for ortho-P was not significant at the 0.05 level, but was significant within a 0.1 level. The significance of this contrast shows the effect of the forage height on water quality constituent levels in runoff. The increased forage mass and height on the ground during the regrowth period prevents the release of the P constituents and suspended solids to runoff.

Table 4-19: Contrasts for broadleaf vs. orchardgrass and grazed vs. regrowth simulations for water quality constituents for all rainfall simulations conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

Contrast	Constituent			
(p-values)	ortho-P	PP	TP	TSS
Concentration (mg/L)				
Broadleaf vs. Orchardgrass	0.1788	0.2356	0.4501	0.6012
Grazed vs. Regrowth	0.0679	<0.0001	<0.0001	<0.0001
Mass (kg/ha)				
Broadleaf vs. Orchardgrass	0.3907	0.4036	0.7455	0.5417
Grazed vs. Regrowth	0.0792	<0.0001	0.0012	<0.0001

4.7 Total suspended solids (TSS) losses from runoff release plots

No significant difference ($p > 0.05$) in mass or concentration losses was observed for any treatment or time x treatment interaction (Table 4-20, Table 4-21).

Table 4-20: Mass and concentration losses and *p*-values for TSS for all rainfall simulations conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

TSS	Mass Response	Concentration Response
***p*-value**	**0.4942**	**0.5629**
Forage Treatment	mg	mg/L
O	402.72	13.02
B	472.94	15.21
p-value	**0.2785**	**0.1584**
Manure Treatment	mg	mg/L
C	321.95	12.21
H	482.90	13.11
L	508.63	19.01

*Means with the same letter designator are not significantly different at the $p < 0.05$ level according to Fisher's protected LSD.

** Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.

Table 4-21: Mass losses and *p*-values for TSS for time interactions with treatments for all rainfall simulations conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

TSS		Interactions with Time and Treatment				
Mass Response			Mass, mg			
Time (Run)	1	2	3	4	5	6
Forage x Time			$p = 0.8030$			
B	2391.1400	396.7500	49.7333	0.0000	0.0000	0.0000
O	2282.5400	1.2342	132.5300	0.0000	0.0000	0.0000
Manure x Time			$p = 0.7069$			
C	1951.0200	-6.2395	11.1667	-8.0908	-8.0908	-8.0901
H	2710.0200	110.5300	19.2156	19.2156	19.2156	19.2156
L	2349.4800	492.6900	243.0100	-11.1248	-11.1248	-11.1248
Forage x Manure x Time			$p = 0.3530$			
CB	1782.2400	22.2496	22.2496	22.2496	22.2496	22.2496
CO	2119.7900	-34.7287	0.0838	-38.4312	-38.4312	-38.4312
HB	2409.7000	198.8100	16.1815	16.1815	16.1815	16.1815
HO	3010.3400	22.2496	22.2496	22.2496	22.2496	22.2496
LB	2981.4700	969.2000	110.7700	-38.4312	-38.4312	-38.4312
LO	1717.4900	16.1815	375.2400	16.1815	16.1815	16.1815

* Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
**Pairing of treatment letters indicates a treatment combination.

While no treatments or interactions were significant ($p > 0.05$), the profile plot indicates a high occurrence of TSS mass and concentration losses in series 1 (Figure 4-8). This is likely due to the excavation activity for plot borders and collection pans that occurred prior to series 1. The decrease and leveling out of the TSS levels during subsequent series indicates that TSS losses were minimal when there was no soil disturbance associated with plot installation. These high TSS losses likely contributed to higher incidences of PP and TP concentrations in series 1 as sediment-bound P was released from the soil surface to runoff.

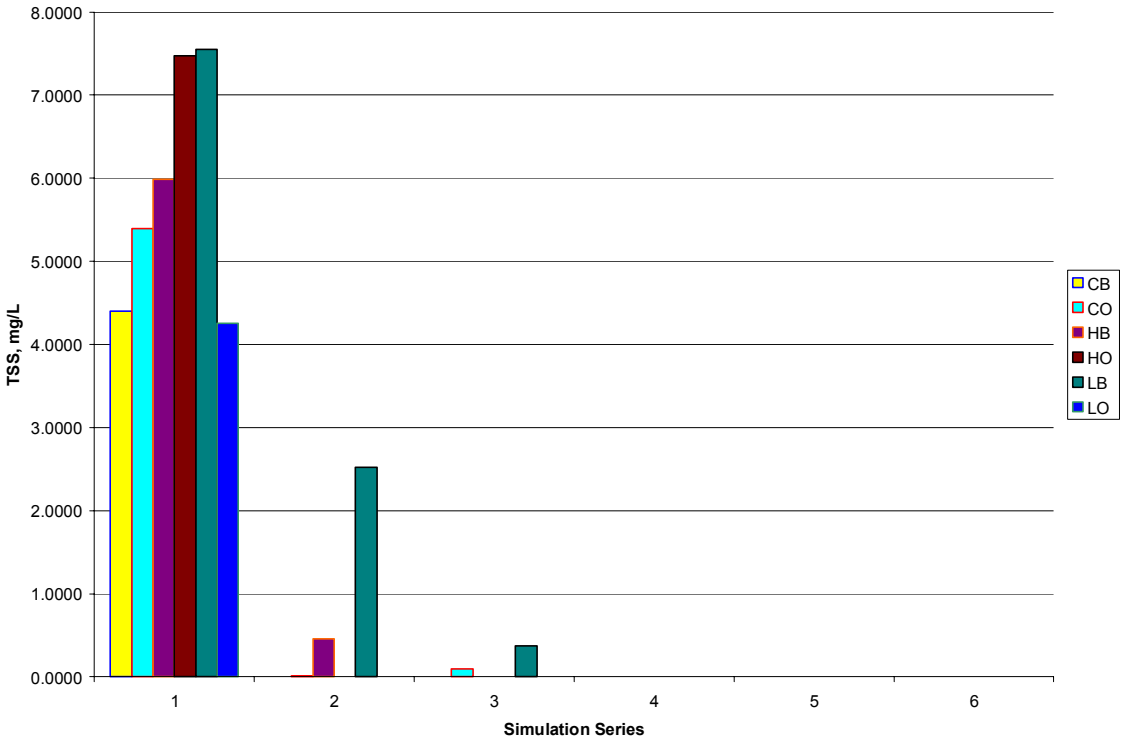

Figure 4-8: Profile plot of TSS losses during all rainfall simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.*

* Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
**Pairing of treatment letters indicates a treatment combination.

4.8 Forage removal from runoff release plots during series 1, 3, and 5

There was no significant effect ($p > 0.05$) on forage removal from manure treatments, manure x forage interactions, or any manure x time combinations. A significant effect ($p < 0.05$) was observed for forage treatment and forage x time combinations (Table 4-22 and Table 4-23).

Table 4-22: Forage and manure treatment removed forage mass and *p*-values for all rainfall simulation series conducted summer 2003 at the Prices Fork Research Farm, Blacksburg, VA.

Removed Forage Mass		Mass Response
Forage Treatment	*p*-value	mg
	0.0020	
O		411.0700
B		487.3800
Manure Treatment		mg
	0.7091	
C		436.5600
H		450.0600
L		461.0500

* Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
**Pairing of treatment letters indicates a treatment combination.

Table 4-23: Forage and manure treatment and time interactions LS Means and *p*-values for removed forage mass.

Removed Forage	Interactions with Time and Treatment					
Mass Response			**Mass, mg**			
Time (Run)	**1**	**2**	**3**	**4**	**5**	**6**
Forage x Time			***p* = <0.0001**			
B	232.4700	0.0000	1102.3200	0.0000	1589.4600	0.0000
O	399.7300	0.0000	862.3000	0.0000	1204.3800	0.0000
Manure x Time			***p* = 0.2411**			
C	276.5000	0.0000	959.7300	0.0000	1391.3500	0.0000
H	348.1200	0.0000	1047.6500	0.0000	1285.0700	0.0000
L	323.6700	0.0000	939.5600	0.0000	1514.3500	0.0000
Forage x Manure x Time			***p* = 0.5459**			
CB	149.2800	0.0000	1021.0300	0.0000	1498.7200	0.0000
CO	403.7200	0.0000	898.4200	0.0000	1283.9700	0.0000
HB	276.2200	0.0000	1233.0200	0.0000	1595.8900	0.0000
HO	420.0200	0.0000	862.2800	0.0000	974.2600	0.0000
LB	271.8900	0.0000	1052.9200	0.0000	1673.7800	0.0000
LO	375.4400	0.0000	826.2000	0.0000	1354.9200	0.0000

* Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
**Pairing of treatment letters indicates a treatment combination.

Further analysis of the Fisher's LSD indicates that the broadleaf forage treatment produced significantly ($p < 0.05$) more dry matter per hectare than the orchardgrass treatments (Table 4-24). This is consistent with the type of forage present in the broadleaf stands. The broader leaf structure of the buckhorn plantain and clovers present in the broadleaf stands yielded more dry matter on a per hectare basis than the fine bladed orchardgrass stand.

Table 4-24: Fisher's LSD for forage treatment in all simulation series.

Removed Mass	**Mass Response**
Forage Treatment	mg
***p*-value**	0.0020
B	487.3800[a]
O	411.0700[b]

*Means with the same letter designator are not significantly different at the $p < 0.05$ level.
** Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
***Pairing of treatment letters indicates a treatment combination.

Table 4-25: Fisher's LSD for forage x time interactions for all simulation series where forage was cut.

Removed Mass			
Mass Response		**Mass, mg**	
Time (Run)	**1**	**3**	**5**
Forage x Time		P < 0.0001	
B	232.4700[a]	1102.3200[c]	1589.4600[e]
O	399.7300[b]	862.3000[d]	1204.3800[c]

*Means with the same letter designator are not significantly different at the $p < 0.05$ level.
** Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
***Pairing of treatment letters indicates a treatment combination.

Forage dry mass yields increased with subsequent simulation series in both orchardgrass and broadleaf treatments. Broadleaf forage produced the highest yield in simulations 3 and 5 as the stands became established. The faster establishment of the orchardgrass stand is indicated by its higher yield in the first simulation series. This is consistent with known establishment patterns of orchardgrass and broadleaf species (Ball et al, 2002).

4.9 Forage mineral P levels

Due to difficulties with the sampling and drying process for forage, reliable forage samples were collected from orchardgrass plots during only series 1 and 3. The removed forage samples were dried and sent to the Virginia Tech Forage Analysis laboratory to determine mineral P concentrations.

There was a significant effect ($p < 0.05$) observed for manure treatment and manure x time combinations (Table 4-26). However, no comparison could be made for the broadleaf stand because of a lack of samples.

Table 4-26: Forage removed mass means and *p*-values and Fisher's LSD comparisons* for manure treatments.

Treatment	Concentration, ppm
p-value	0.0040
L	0.0046[a]
H	0.0851[a]
C	0.0912[a]

*Means with the same letter designator are not significantly different at the $p < 0.05$ level.
** Treatment letters: B- Broadleaf, O- Orchardgrass, C-Control manure, H-High manure, L- Low manure.
***Pairing of treatment letters indicates a treatment combination.

Further analysis with the manure x time interaction data indicated that there was no significant difference ($p > 0.05$) in removed mass for the first series sampling and that the low stocking rate manure application was the only significant factor in the series 3 sampling.

Mineral P concentrations and removed mass was not observed to be different. While the removed mass of forage did differ over sample times and manure treatments, the concentrations detected in the forage did not differ. This indicates that the forage did not change its P uptake for growth as the forage stand established over the season.