Evaluation & Management of Vegetation Along Virginia Roadsides

2006 Annual Report

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Project 1 Variety Field Research

1.1 Cool-Season Seeded Turfgrass Trials

Objective: To evaluate establishment, persistence, and performance of cool season seeded turfgrass cultivars for possible inclusion on VDOT's Approved Species and Cultivars List (RD-4).

1.1.1 2002 Cool-Season Evaluations at Roanoke

Planted in Fall of 2002, final evaluations of this trial were collected in Spring, 2006. The trial site was located in Roanoke on Northbound I-581 at the I-81 intersection. Appropriate additions were made to update the Approved Species and Cultivars List (RD-4).

Tall Fescue[1]

Cultivar	Producer	% cover
Arabia	Simplot-Jacklin	87.5
Arid 3	Simplot-Jacklin	87.5
Arid II	Simplot-Jacklin	87.5
Barlexas	Barenbrug USA	95.0
Barrera	Barenbrug USA	97.5
Barrington	Barenbrug USA	90.0
Bravo	Lesco	92.5
Coronado Gold	Turf Seed	97.5
Coyote	Landmark Seed	97.5
Crewcut II	Seed Research	97.5
Dynasty	PickSeed	42.5
Endeavor	Turf Seed	95.0
Focus	TMI	100.0
Grande	Seed Research	90.0
Maximize	Turf Seed	95.0
Millennium	TMI	90.0
Mustang 3	Pick Seed	97.5
Olympic Gold	Turf Seed	92.5
Pure Gold	Turf Seed	97.5
Quest	Simplot-Jacklin	92.5
Rendition	Smith Seed	82.5
Southeast	Landmark Seed	82.5
SR 8210	Seed Research	90.0
SR 8250	Seed Research	92.5
SR 8500	Seed Research	82.5
SR 8600	Seed Research	100.0
Stetson	Lesco	90.0
Tar Heel	Turf Seed	90.0
TF 66	Barenbrug USA	90.0

Tracer	Barenbrug USA	87.5
Wolfpack	Turf Seed	100.0

1 Requires minimum plot coverage of 70% or greater over a three year evaluation period to be included on the VDOT Approved Species and Cultivar list.

Chewings Fescue[1]

Cultivar	Producer	% cover
Bridgeport	Barenbrug USA	87.5
Brittany	Lesco	90.0
Intrigue	TMI	80.0
Sandpipers	Seed Research	75.0
SR 5100	Seed Research	85.0
Tiffany	Turf Seed	75.0

Hard Fescue[1]

Cultivar	Producer	% cover
Aurora Gold	**Turf Seed**	
Defiant	**Lesco**	
Discovery	**Turf Seed**	
Hardtop	**Barenbrug USA**	
Minotaur	**TMI**	
Osprey	**Seed Research**	
Rescue 911	**Simplot-Jacklin**	
Scaldis II	**Seed Research**	
SR 3100	**Seed Research**	

Red Fescue[1]

Cultivar	Producer	% cover
Bargena III	Barenbrug USA	87.5
Jasper II	PickSeed	97.5
Shademark	Lesco	87.5
Shademaster II	Turf Seed	85.0

Perennial Ryegrass[1]

Cultivar	Producer	% cover
Allsport	Lesco	42.5
ASAP	Simplot-Jacklin	72.5
Barlenium	Barenbrug USA	52.5
Goalkeeper	Simplot-Jacklin	80.0
Legacy II	Lesco	90.0
Linedrive	Lesco	77.5
Peak	Barenbrug USA	67.5
Pinnacle II	Barenbrug USA	55.0
Pirouette	Barenbrug USA	80.0
Pizzazz	TMI	77.5

Premier II	Barenbrug USA	50.0
Prosport	Lesco	47.5

1 Requires minimum plot coverage of 70% or greater over a three year evaluation period to be included on the VDOT Approved Species and Cultivar list.

Kentucky Bluegrass[1]

Cultivar	Producer	% cover
Baritone	Barenbrug USA	67.5
Baron	Barenbrug USA	70.0
Baronie	Barenbrug USA	67.5
Barzan	Barenbrug USA	87.5
Beethoven	Turf Seed	87.5
Blue Max	Turf Seed	92.5
BlueStar	Turf Seed	87.5
Brooklawn	TMI	95.0
Canon	Seed Research	85.0
Denim	Turf Seed	90.0
Langara	PickSeed	90.0
Midnight Star	Turf Seed	70.0
Shamrock	Lesco	62.5
SR 2100	Seed Research	60.0
Unique	PickSeed	97.5
Voyager	Turf Seed	92.5

Miscellaneous Grasses[1]

Cultivar	Producer	% cover
Barcampsia Tufted Hairgrass	Barenbrug USA	85.0
Barkoel *Koeleria cristata*	Barenbrug USA	75.0
Barleria *Koeleria cristata*	Barenbrug USA	82.5
Barpressa Canadien bluegrass	Barenbrug USA	60.0
Pro Am *Poa trivialis*	Lesco	15.0
SR 7100 Colonial Bentgrass	Seed Research	80.0

1 Requires minimum plot coverage of 70% or greater over a three year evaluation period to be included on the VDOT Approved Species and Cultivar list.

1.1.2 2004 Cool-Season Evaluations at Blacksburg

Planted Spring, 2004, final evaluations of this trial will be collected Spring, 2007. The trial site is located at the Virginia Tech Turfgrass Research Center in Blacksburg.

1.1.3 2006 Cool Season Evaluations at Three Virginia Locations

To provide timely additions to the Approved Species and Cultivar List (RD4), entries for cool-season evaluation trials were solicited and initiated during the 2006 season. Three sites across the state were selected to represent the diverse climatic regions of the state of Virginia. Trials were initiated at: Harrisonburg at exit 251 on I-81; the Northern Piedmont AREC in Orange; and the Southern Piedmont AREC in Blackstone.

The trials at Harrisonburg and Orange included the full complement of solicited cool-season species and cultivars for evaluation. The trial in Blackstone included only tall fescues and Texas or Hybrid bluegrasses (Texas x Kentucky bluegrass).

There were 210 entries from 17 species submitted to be considered for placement on the Approved List. Each entry is replicated three times at each site to ensure a fair representation of its establishment and persistence capabilities. At the end of the three year evaluation period an entry must have established and maintained 70% plot coverage to placed on the Approved Species and Cultivars List.

Entries with assigned plot locations and plot maps for the 2006 trials are included below.

TALL FESCUE

101 245 317 Apache III
102 212 306 Aristotle
103 247 318 ATF 1235
104 205 303 Barlexas II
105 206 321 Barrera
106 217 307 Bingo
107 243 316 Bonsai 3000
108 201 301 Cochise II
109 238 314 Coyote II
110 210 305 Dakota
111 228 311 Dynamic
112 211 323 EA 171
113 213 324 Einstein
114 232 313 Falcon IV
115 229 329 Fidelity
116 233 331 Finelawn Elite
117 248 336 Firebird
118 244 334 Firenza
119 234 339 Five Point
120 222 308 Gooden
121 240 315 Grande II
122 239 332 Greenkeeper
123 218 325 Houndog 5
124 219 338 Houndog 6
125 226 310 Inferno
126 227 328 Jaguar 4
127 224 309 Kalahari
128 214 337 Lexington
129 230 312 Magellan
130 202 319 Ninja II
131 231 330 Padre
132 220 343 Rhizing Star
133 235 344 Scorpion II
134 225 327 Serengeti
135 203 302 Shelby
136 236 347 Shenandoah II
137 204 320 Silverhawk
138 215 342 Sitka
139 237 348 Six Point
140 221 346 Solara
141 241 333 SR 8550
142 242 340 STR 8LMM
143 216 345 Tahoe
144 246 335 Tar Heel II
145 208 304 Tempest
146 207 341 TF 66
147 209 322 Turbo
148 223 326 Wpeze
149 249 349 Virtuosa
150 250 350 2nd Millenium
151 251 351 Taos
152 252 352 Avenger
153 253 353 Constitution
154 254 354 Titanium
155 255 355 Tuxedo
156 256 356 Paraiso
157 257 357 Trooper
158 258 358 Forrest Green

HARD FESCUE

101 212 308 Aurora II
102 213 311 Aurora Gold
103 211 307 Berkshire
104 204 304 Ecostar
105 207 306 Fire Fly
106 206 305 Gotham
107 208 310 Nordic
108 209 312 Reliant II
109 205 309 Rescue 911
110 202 302 Rhino
111 203 303 Ridu
112 214 313 Stonehenge
113 201 301 Viking
114 210 314 Harpoon
115 215 315 Granite
116 216 316 Chariot
117 217 317 Heron

Sheeps Fescue

101 205 305 Azure
102 204 301 Blacksheep
103 203 304 MX-07
104 202 302 Quatro
105 201 303 Whisper
106 206 306 Dall

Chewings Fescue

101 207 303 Ambrose
102 208 305 Culumbra II
103 206 309 J-5
104 204 306 Jamestown V
105 205 307 Longfellow II
106 201 308 Musica
107 203 304 Salisbury
108 209 302 Treazure
109 202 301 Zodiac
110 210 310 Compass
111 211 311 Chancellor

Red Fescue

101 207 305 Aruba
102 208 313 Audubon
103 205 307 Cindy Lou
104 203 308 Crossbow
105 211 302 Florentine GT
106 210 303 Foxfire
107 201 310 Gibralter
108 212 312 Inverness
109 213 301 Loxia
111 204 314 Trapeze
112 209 304 Wendy Jean
113 202 309 Weston
114 206 306 WP 888
115 215 315 Beacon
116 216 316 Navigator
117 217 317 Foxy
118 218 318 SeaBreeze GT

Perennial Ryegrass

101 205 303 Buena Vista
102 220 308 Cabo II
103 208 312 Covet
104 201 311 Deleware XL
105 209 317 Edison
106 214 306 Esquire
107 221 320 Fiji
108 207 304 Frontier
109 238 314 Fusion
110 215 318 Gator 3
111 236 313 Gray Star
112 239 326 Icon
113 216 328 IS-PR 268
114 222 329 Kokomo 2
115 227 301 Line Drive GLS
116 217 332 MBH2
117 223 309 Monterey 3
118 206 316 Overdrive
119 210 327 Palace
120 228 323 Palmer IV
121 229 330 Palmer V
122 230 333 Panther GLS
123 234 305 Peregrine
124 204 302 Phenom
125 231 335 Prelude GLS
126 232 337 Prelude IV
127 211 331 Presidio
128 212 334 Primary
129 213 336 Priority
130 225 310 Prototype
131 233 339 Repell GLS
132 224 321 Revenge GLX
133 202 315 Roadster
134 203 338 Saint
135 237 325 Silver Dollar
136 235 324 SR 4550
137 226 322 Wayfarer
138 218 307 WP 13206
139 219 319 WP 17018
140 240 340 Acappella
141 241 341 MDPDarkstar II
142 242 342 Apple GL
143 243 343 Flash II
144 244 344 Stellar
145 245 345 Cruiser
146 246 346 Barlennium
147 247 347 Pinnacle II

Kentucky bluegrass

101 217 303 Alexa
102 208 307 Appalachian
103 203 309 Avid
104 213 305 Blue Chip
105 201 311 Comrade
106 205 308 Deep Blue
107 218 313 Diva
108 211 306 Durham
109 204 319 Dynamo
110 219 321 Eagleton
111 209 317 Evora
112 215 304 Glenmont
113 220 324 Guinness
114 221 325 Hunnington
115 225 302 Kingfisher
116 214 315 Liberator
117 226 301 Midnight
118 212 316 Mongoose
119 227 312 Moonlight
120 228 320 Moonshine
121 222 326 Mystere
122 223 327 Preakness
123 224 328 Princeton 105
124 206 318 PST-1121
125 210 322 Rhythm
126 216 314 Shamrock
127 202 310 Wildhorse
128 207 323 1B7-308
129 229 329 Concerto
130 230 330 Denali
131 231 331 Corsair
132 232 332 A98-689
133 233 333 NA-3261
134 234 334 NA-3271
135 235 335 Cadet
136 236 336 Mystique
137 237 337 Bariris
138 238 338 Baron

MISCELLANEOUS

101 203 301 Fults Alkaligrass
102 201 302 Salty Alkaligrass
103 202 303 Fults II Alkaligrass
104 206 305 SR 3210 Blue Fescue
105 204 304 Duo *Festulolium*
106 205 306 Reubens Canada Bluegrass
107 207 309 Streaker Redtop
108 211 310 GolfStar Idaho Bentgrass
109 209 307 Cobra 2 Creeping Bentgrass
110 208 311 SR 7150 Colonial Bentgrass
111 210 308 Tiger II Colonial Bentgrass
112 214 316 Long Horn Texas bluegrass
113 215 312 Fire and Ice Texas bluegrass
114 216 313 SPTR 2LM95 Hybrid bluegrass
115 212 314 Armadillo Hybrid Bluegrass
116 213 315 Fahrenheit 90 Hybrid Bluegrass

Harrisonburg

Tall Fescue
Hard Fescue
Red Fescue
Chewings Fescue
Kentucky Bluegrass

Sheeps Fescue

Perennial Ryegrass

Alkaligrass
etc
Agrostis
Texas/Hybrid Bluegrass

101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	101
130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	102
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301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	202
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320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	315	316

Northern Piedmont AREC – Orange

Hard Fescue *Red Fescue* *Sheeps Fescue / Chewings Fescue* *Kentucky Bluegrass / Tall Fescue* *Perennial Ryegrass / Alkaligrass / etc / Texas/Hybid Blue.* *Agrostis*

101	102	103	101	102	103	101	102	103	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	101	102	103	104	105	106	107	108	109	110
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217	301	302	218	301	302	205	206	207	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	322	323	324	325	326	327	328	329	330	331	332	333	
303	304	305	303	304	305	208	209	210	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	334	335	336	337	338	339	340	341	342	343	344	345	
306	307	308	306	307	308	211	301	302	255	256	257	258	301	302	303	304	305	306	307	308	309	310	311	312	101	102	103	201	202	203	301	302	303	107	346	347	
309	310	311	309	310	312	303	304	305	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	104	105	106	204	205	206	304	305	306	108	109	110	
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315	316	317	316	317	318	309	310	311	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	214	215	216	312	313	314	315	316	307	308	309	310	311	

Southern Piedmont AREC – Blackstone

Tall Fescue *Texas/Hybrid Bluegrasses*

101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154
155	156	157	158	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223
224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250
251	252	253	254	255	256	257	258	301	302	303	304	305	306	307	308	309	310	311	312	313	314	112	113	114	115	116
315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	212	213	214	215	216
337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	312	313	314	315	316

1.2 Warm-Season Seeded Turfgrass Trials

Due to April, 2006 hiring of new Roadside Vegetation Management personnel, anticipated establishment of warm-season turfgrass trials were postponed until 2007. Time and climate restrictions did not allow sufficient time to solicit and initiate this trial within warm-season species developmental requirements.

Evaluation trials will be undertaken in multiple regions within the state during the 2007 growing season.

Project 2 Fertility, Mowing, and Misc. Management

2.1 Mowing Management Studies

Objective: To determine the optimum agronomic and economic mowing frequency of fine fescue, tall fescue, Kentucky Bluegrass, and bermudagrass.

Due to genetic variability in inflorescence development between cultivars, it has proven difficult to determine an optimum mowing date specific to each species. We recommend continued utilization of past recommendations provided to VDOT personnel by Virginia Tech.

See Appendix A for region specific recommendations on scheduling mowing events

2.2 Re-assessing VDOT initial fertilizer and lime specifications

Objective: To define the best fertilizer practices for establishing turfgrass using VDOT methods on Coastal Plain, Piedmont and Valley and Ridge typical soil types in Virginia.

The report is presented below. A summary of each of the four studies are presented together, followed by the individual studies in their entirety.

Evaluation of the Effect of Lime, Phosphorus and Nitrogen on Tall Fescue: A Set of Four Greenhouse Studies

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Summary Report

A. Comparing the Standard VDOT Specified Lime Application Rate with Lime Rates derived from Soil Tests on Performance of Tall Fescue in Three soils from Virginia

- **2 Treatments:-** Lime ($CaCO_3$, lab grade) rate from VDOT standard (2 T/A) and from soil tests (Cburg-2.75 T/A; Gloucester-2.5 T/A; Orange-4.5 T/A)
- **Soils Used:** Christiansburg, Gloucester and Orange
- **Fertilizers:** N, P, K from VDOT 15-30-15 that is 30% slow release – 90 lb/A (Applied April 15, 2005)
- **Seed:** Jaguar TF (Seeded April 18, 2005)
- **Result:** Soil test the soil to provide the most accurate rate of lime.

B. Comparing Surface Applied Lime with Soil Incorporated Lime for the Performance of Tall Fescue Grown in Three soils from Virginia 2

- **Treatments:** Lime ($CaCO_3$, lab grade) rate from soil tests (Cburg-2.75 T/A; Gloucester-2.5 T/A; Orange-4.5 T/A). Half of pots were surface applied and for other half lime incorporated in each pot (soil and lime mixed in plastic bag and then added back to pot).
- **Soils Used:** Christiansburg, Gloucester and Orange
- **Fertilizers:** N, P,K from VDOT 15-30-15 that is 30% slow release – 90 lb/A. (Applied April 15, 2005)
- **Seed:** Jaguar TF (Seeded April 18, 2005)
- **Result:** Surface applied lime produced nearly the same plant growth as incorporated.

C. Comparing VDOT vs. Soil Test Derived Rates of Phosphorus.

- **5 Treatments:** Pots treated with 0,100, 200, 300 and 400 lb/A of P_2O_5. Used $CaH_4(PO_4)_2$.
- **Lime:** Lime ($CaCO_3$, lab grade) rate from soil tests (Cburg-2.75 T/A).
- **Soils Used:** Christiansburg
- **Fertilizers:** N is from Mesa at 90 lb/A, K_2O from K_2SO_4 (90 lb/A). (Applied April 15, 2005)
- **Seed:** Jaguar TF (Seeded April 18, 2005)
- **Result:** The higher rate of P produced the best growth of tall fescue. These higher rates can no longer be used once the VDOT Nutrient Management Plan of July 1, 2006, is implemented.

D. Compare the Performance of Tall Fescue Amended with Three Rates of 30% Slowly Available Formulations of N.

- **Treatments**: No N (Control), 45, 60 and 90 lb/A of N from VDOT 15-30-15 that is 30% slow release
- **Lime**: Lime ($CaCO_3$, lab grade) rate from soil tests (Cburg-2.75 T/A; Gloucester-2.5 T/A; Orange-4.5 T/A).
- **Soils Used:** Christiansburg, Gloucester, and Orange
- **Fertilizers:** For all pots >K_2O from K_2SO_4 (90 lb/A) and P_2O_5 from $CaH_4(PO_4)_2$ (180 lb/A). Will have to make sure all pots have equal amounts because the fertilizer will deliver some of the K and P. (Applied April 15, 2005)
- **Seed:** Jaguar TF (Seeded April 18, 2005)
- **Pots needed:**4 treatments x 5 reps x 3 soils = 60 pots. (Filled April 7, 2005)
- **Result:** Higher rates, 60-90 lbs/A, of N produced the best growth in two of the three soils tested.

A. Comparing the Standard VDOT Specified Lime Application Rates with Lime Rates derived from Soil Tests on Performance of Tall Fescue in Three soils from Virginia

Objective: To compare the performance of tall fescue grown in soil that was either amended with the standard VDOT lime specification or amended with lime as prescribed by laboratory soil tests.

Methods and Materials: In this greenhouse study, initiated April 18, 2005, tall fescue 'Jaguar II' seed was planted into native C-horizon Christiansburg, Gloucester, and Orange soils with pH of 5.4, 5.0, and 4.4, respectively. The Christiansburg soil is clayey and high in exchangeable aluminum, the soil from Gloucester is a sandy loam, and the soil from Orange is high in clay and iron (very red) (Table A.1).

Table A.1. Analysis of Christiansburg C-horizon soil used in the study.

	Christiansburg	**Gloucester**	**Orange**
Element(Acid Extractable)	**lb/A**	**lb/A**	**lb/A**
Phosphorus (P)	4 (L)	13 (M-)	75 (H)
Potassium (K)	99 (M-)	90 (M-)	179 (H-)
Calcium (Ca)	1563 (H-)	559 (L+)	732 (M-)
Magnesium (Mg)	145 (H-)	95 (M-)	111 (M)
pH	5.4	5.0	4.4

Each quart size plastic pot was filled with 700g of dried soil. An unbleached coffee filter was placed on the inside of the pot (4" round) to retain the soil. Lab grade powdered lime (as $CaCO_3$) at either the VDOT standard rate of 2,000 lb/A or soil test derived rate (target soil pH of 6.5) were incorporated into the soil in each pot on April 7 (Table A.2). The pots were irrigated with water to field capacity, and allowed to dry for two days and then re-watered. Three wet/dry cycles were completed to initiate the lime and soil chemical reactions, thus raising the soil pH. Nitrogen (N), phosphorus (P) and potassium (K) were supplied in equal amounts to all pots by a surface application of a slow release (SR) formulation of the current fertilizer used by VDOT on April 15th. This 15-30-15 formulation contains 30% (WIN) slowly available N from (4.5% urea formaldehyde). The seed (100 lb/A or 0.11g/pot) was applied on April 18th to the surface of each pot. This amount of seed resulted in a very uniform stand with an average of 42-48 seedlings per pot. The pots were watered daily with a fine mist to keep the seed from moving down the sides of the pot. When the roots were firmly established, the pots were irrigated with drip irrigation two times daily, 1 minute per watering, to minimize leaching of fertilizer.

The pots were arranged in a randomized block design. The two liming treatments were replicated five times for each soil type. The plants were maintained for 131 days after sowing. Grass population per pot was evaluated for **height** about once a week, **clipping dry weight** (95)[1], and **re-growth height** 36 days after clipping (day 131).

Table A.2. List of treatments and corresponding lime applied to the soil surface prior to seeding tall fescue.

Soil Type	**Amendments Applied**	**Lime (T/A)**
Christiansburg	Std VDOT	2.00
Christiansburg	Soil Test Lime	2.75
Gloucester	Std VDOT	2.00
Gloucester	Soil Test Lime	2.50
Orange	Std VDOT	2.00
Orange	Soil Test Lime	4.50

[1] Grass was cut at the soil surface. The grass recovered from this drastic clipping method, and the re-growth was measured.

Results: The important question that we wanted to answer was: Should we pH test roadside soils or should we apply a VDOT "one-fit-all" rate of lime? We also wanted to specify which provided the best quality of tall fescue growth. The answer to this question is that a "one-fit-all" approach is not acceptable in Virginia because the soils across the state are very different. In our study, the Gloucester soil represents what is typically found in the Coastal Plain region; the Orange soil represents typical pH from the Piedmont region; and the Christiansburg soil represents soil from the Valley and Ridge region.

The lime applied to the Christiansburg soil for both the "soil test" rate (2.75 T/A) and the "standard VDOT" (2 T/A) rate was not adequate to elicit a positive plant growth response, mainly because the lime failed to raise the soil pH past 5.8 (Table A.3). The target pH for all three soil types was 6.4 (Table A.4). Because the Christiansburg soil was high in aluminum and was therefore strongly buffered, it resisted pH change even with the addition of 2 T/A of lime. In this study, we should have added more lime than was recommended by Virginia Tech's Soil Testing Lab in April 2005. Since that time, the Soil Testing Lab has moved to creating a "buffered soil pH test" system. With this newer test, a more accurate about of lime would be recommended. The plants grown in the Christiansburg soil increased in height until about 54 days after seeding (Figure A.1), after which the height leveled off. At 89 days after seeding, there was little difference in height and weight of plants grown with or without lime. This may have been because at the starting pH of 5.4, the tall fescue was able to grow well enough as compared to lime treated soil. This is a testament to the adaptability of this grass.

The "soil test" derived lime rate (2.5 T/A) for the Gloucester soil differed by only one half of a ton in comparison to the "standard VDOT" rate (2 T/A), and as expected, the resulting pH and plant growth responses were very similar. The plants grown in this soil increased in height until about 54 days after seeding, similar to the Christiansburg plants. After 89 days after seeding, there was a significant difference between plants grown in soil that received lime and those that did not receive lime.

For the last soil examined (from Orange) the "standard VDOT" rate (2 T/A) would have significantly under-limed the test soil. The "soil test" rate (4.5 T/A) of lime raised the pH to the desired level of 6.4, while the "standard VDOT" rate pH was only at 5.9. The height 89 days after seeding and re-growth 131 days after seeding of grass treated with zero, "std VDOT" and "soil test" lime rates were not different. However, the final biomass for plants grown in the "soil test" treatment was significantly greater than all other treatments (Figure A.2).

It is our recommendation that site-specific soil tests be used to determine the pH of soils and lime rates prior to lime applications. Sometimes the "soil test" rates will be similar to the "standard VDOT" rate of 2 T/A; however, on occasion, the standard rate will not be adequate to support long term growth of tall fescue. Lime is relatively inexpensive and easy to apply. Soil at pH values around 6.4 will provide nutrients in a form that is most available to plants, will help conserve the loss of nutrients to the environment by promoting plant and root uptake, will keep soil erosion from occurring, and will better sustain legumes.

Table 1.1-3. Height and weight of grass leaves at specific "Number of Days after Seeding".

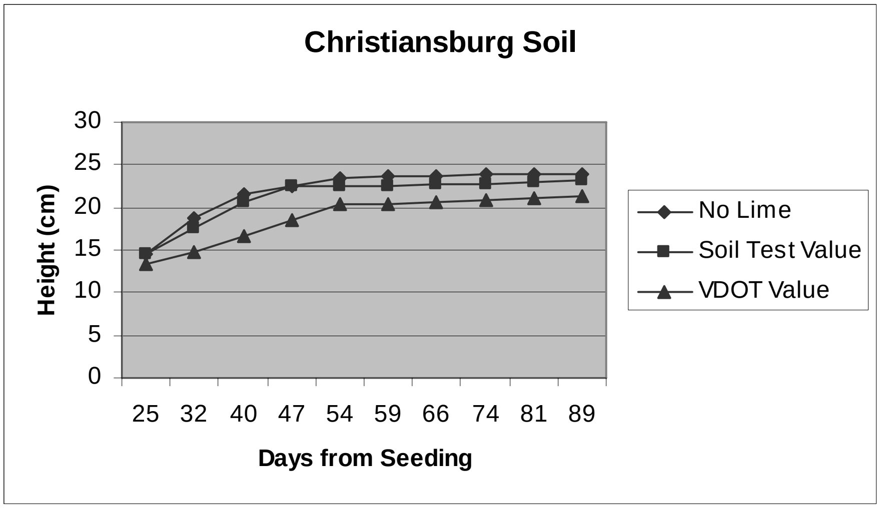
Amendments Applied	Soil Type	Lime (T/A)	Day 89 Height (cm)	Day 131 Re-growth Height (cm)	Weight on Day 89 (g)	Soil pH 131 Days
No Lime	Christiansburg	0	23.9a	6.2a	2.6a	5.1b
Std VDOT	Christiansburg	2.00	23.2a	5.6a	2.0a	5.7a
Soil Test	Christiansburg	2.75	21.3a	5.2a	2.3a	5.8a
No Lime	Gloucester	0	24.8b	8.9b	2.8c	4.9b
Std VDOT	Gloucester	2.00	28.1ab	11.0a	4.5b	6.2a
Soil Test	Gloucester	2.50	29.9a	11.0a	5.3a	6.1a
No Lime	Orange	0	31.6a	10.9a	4.2b	5.4b
Std VDOT	Orange	2.00	31.6a	11.9ab	4.7b	5.9b
Soil Test	Orange	4.50	31.6a	13.2a	5.6a	6.5a

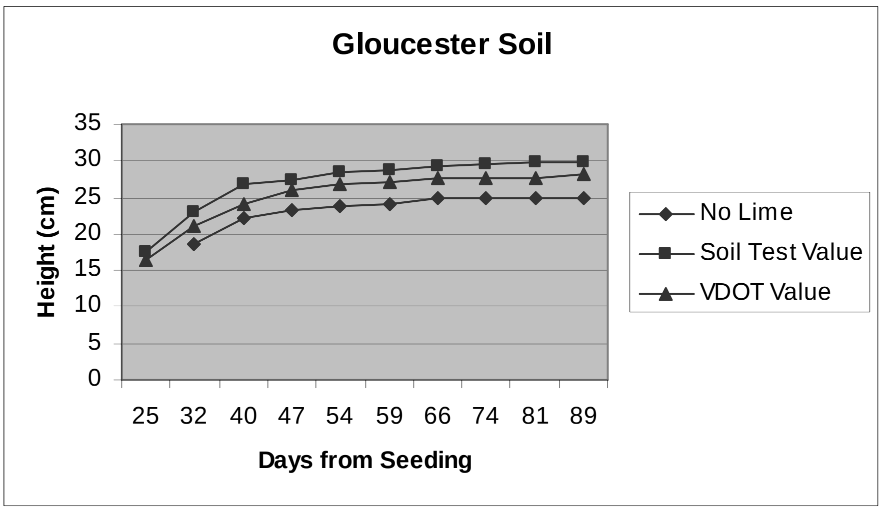
* Means within a column (for each soil type) followed by the same letter are not significantly different at the 5% level according to Student, Newman and Kuels test.

Table A.4. Results of pH of soil 131 days after sowing seed. Three treatments were a control (no lime applied), standard VDOT rate of lime (2 T/A) or lime determined from a soil test.

Amendments Applied	Soil Type	Lime(T/A)	pH 131 Days after Sowing	Deviance from Target pH 6.4
No Lime	Christiansburg	0	5.1	-1.4
Std VDOT	Christiansburg	2.00	5.7	-0.8
Soil Test	Christiansburg	2.75	5.8	-0.6
No Lime	Gloucester	0	4.8	-1.6
Std VDOT	Gloucester	2.00	6.1	-0.3
Soil Test	Gloucester	2.50	6.1	-0.3
No Lime	Orange	0	5.4	-1.0
Std VDOT	Orange	2.00	5.9	-0.5
Soil Test	Orange	4.50	6.4	0

Figure A.1. The height (cm) per day after seeding of tall fescue for each liming treatment until 89 days after seeding. Data are shown for each soil type.





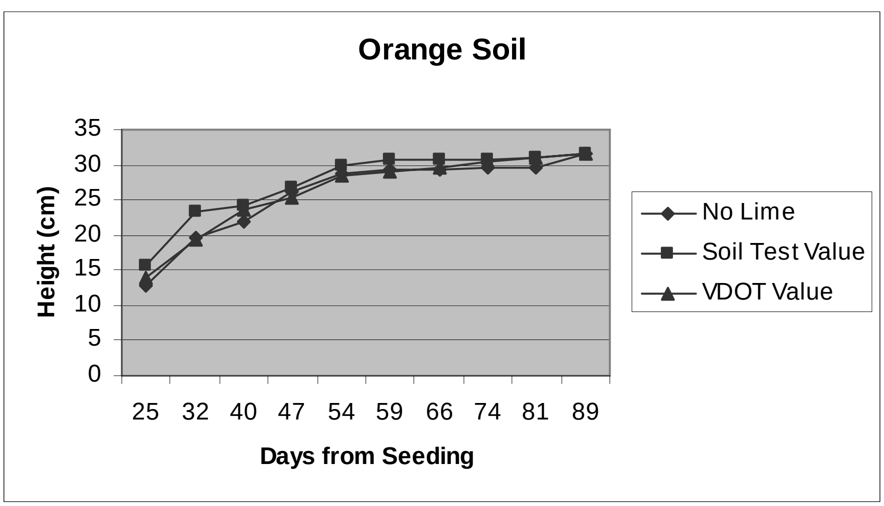
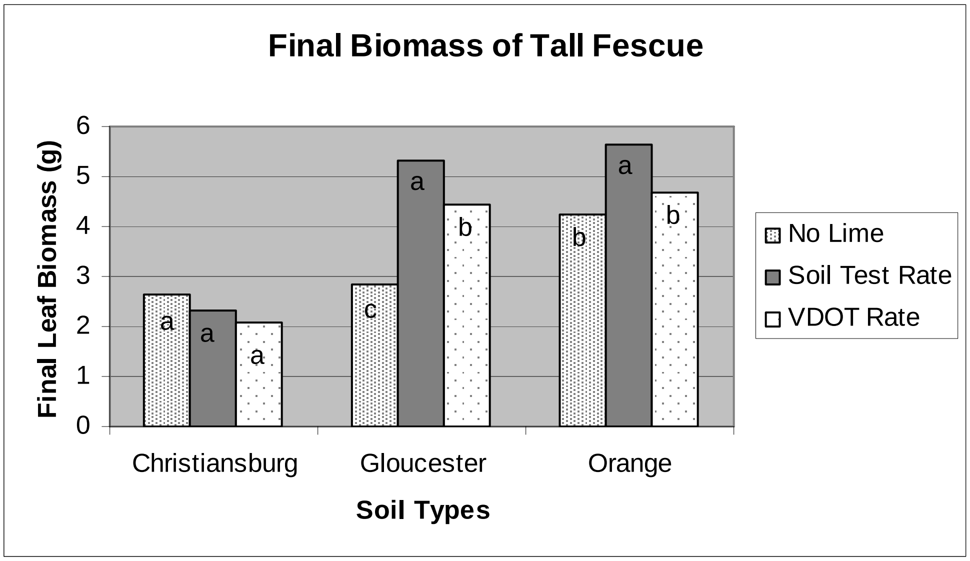


Figure A.2. The weight (grams) of the tall fescue for each liming treatment 89 days after seeding. Data are shown for each soil type. All lime treatments, within each soil type, with the same letter were not significantly different at the 5% level according to Student, Newman and Kuels test.



B. Comparing Surface Applied Lime with Soil Incorporated Lime on the Performance of Tall Fescue Grown in Three soils from Virginia

Objective: To evaluate the performance of tall fescue grown in three types of soil that were treated with lime. The lime was either surface-applied (mimicking hydraulic seeder) or incorporated into the soil.

Methods and Materials: This greenhouse study was also initiated on April 18, 2005. The same soil and seed were used as stated in section A.1.

Each quart size plastic pot was filled with 700g of dried soil. An unbleached coffee filter was placed on the inside of the pot (4" round) to retain the soil. Lab grade powdered lime (as $CaCO_3$) at the soil test derived rate (6.5 target soil pH) was either incorporated into the soil of each pot or surface applied on April 7. Christiansburg soil received 2.75 T/A of $CaCO_3$, Gloucester soil received 2.50 T/A of $CaCO_3$, and the Orange soil received 4.50 T/A of $CaCO_3$ (Table 1.2 – 1). The pots were irrigated with water to field capacity, and allowed to dry for two days and then re-watered. Three wet/dry cycles were completed to initiate the lime and soil chemical reactions, thus raising the soil pH. Nitrogen (N), phosphorus (P) and potassium (K) were supplied in equal amounts to all pots by a surface application of a slowly released (SR) formulation of the current fertilizer used by VDOT on April 15th. This 15-30-15 formulation contains 30% (WIN) slowly available N from (4.5% urea formaldehyde). The seed (100 lb/A or 0.11g/pot) was applied to the surface of each pot on April 18th. The pots were watered daily with a fine mist to keep the seed from moving down the sides of the pot. When the roots were firmly established, the pots were irrigated with drip irrigation two times daily, 1 minute per watering, to minimized leaching of fertilizer.

The pots were arranged in a randomized complete block design. The two liming application treatments were replicated five times for each soil type. A control of no lime was used (5 pots). The plants were maintained for 131 days after sowing. Grass population per pot was evaluated for **height** about once a week, **clipping dry weight** (95)[2], and **re-growth height** 36 days after clipping (day 131).

Table B.1. List of treatments and corresponding amendments that were applied to the soil surface at the time of seeding tall fescue.

Soil Type	Lime (T/A)	Type of Lime Application
Christiansburg	2.75	Surface
Christiansburg	2.75	Incorporated
Gloucester	2.50	Surface
Gloucester	2.50	Incorporated
Orange	4.50	Surface
Orange	4.50	Incorporated

Results: The question proposed for this study was: Is it better to *incorporate* or *surface apply* lime on roadside soils? Once again, we used three soil types representative of the major soil regions of Virginia. The pH values of the limed soils, no matter if the lime was mixed or surface applied, were not significantly different (Table B.1). This was also true for the height of the grass at the end of the study and for measured re-growth. However, the dry weights of the biomass 89 days after seeding were significantly different for the grass grown in the Gloucester soil. Also, it is evident from the overall height response of the tall fescue in the Christiansburg and Orange soils, the lime-incorporated soil grown plants tended to be slightly taller than in pots where the lime was surface applied (Figure B.1). We do not know why this occurred. We can speculate that it may have had

[2] Grass was cut at the soil surface. The grass recovered from this drastic clipping method, and the re-growth was measured.

something to do with the fact that the Gloucester soil had a higher sand content than the Christiansburg and Orange soils.

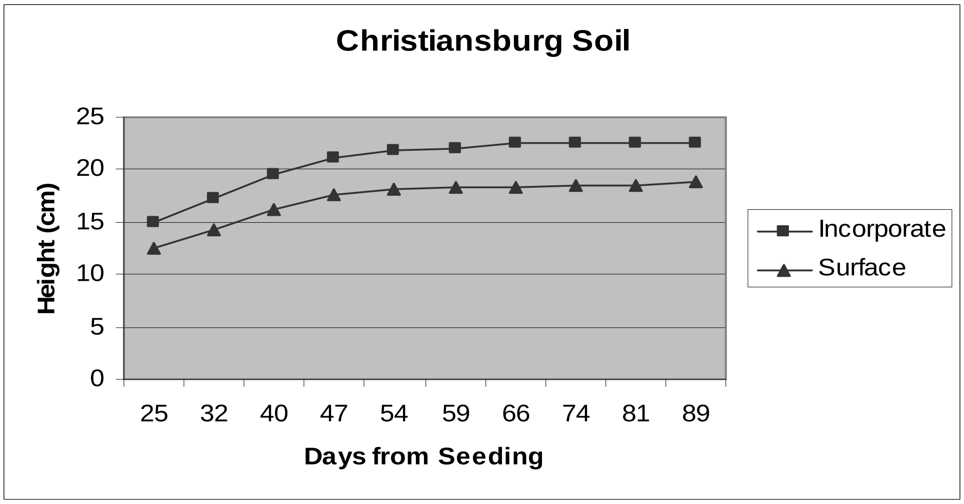
At this time, we cannot definitively report that either soil incorporation or surface applied lime is a better method of applying lime. It appears that in this greenhouse pot study, both surface and incorporated methods are adequate. The application of lime through a hydraulic seeder results in surface applications. This is no different from liming no-till corn. Both appear to be fully acceptable management practices at this time.

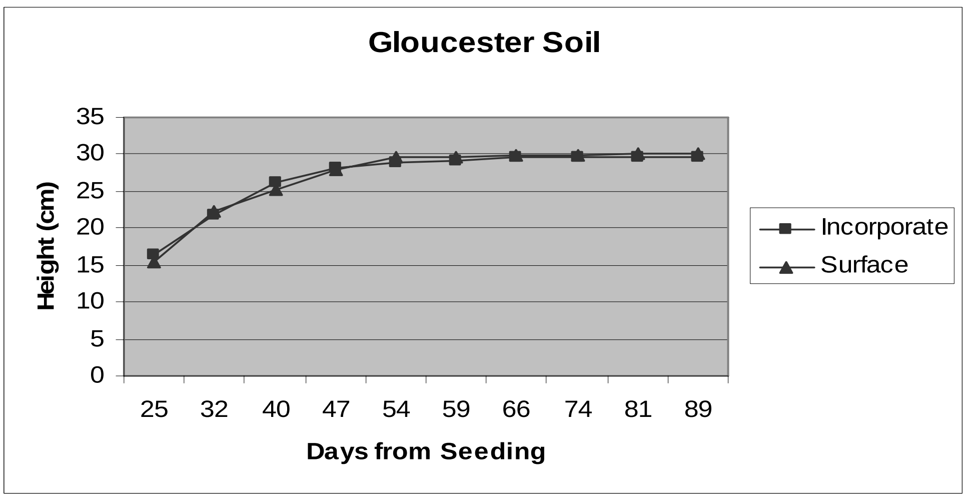
Table 1.2-2. Height and weight of grass at specific "Number of Days from Sowing".

Type Lime Application	Soil Type	Lime (T/A)	Day 89 Height (cm)	Day 131 Re-growth Height (cm)	Weight on Day 89 (g)	Soil pH 131 Days
No Lime	Christiansburg	0	23.9a	6.2a	2.6a	5.1b
Surface	Christiansburg	2.75	18.8b	5.4a	1.9b	5.8a
Incorporated	Christiansburg	2.75	22.5ab	5.6a	2.2ab	6.1a
No Lime	Gloucester	0	24.8b	8.9a	2.8c	5.4b
Surface	Gloucester	2.50	30.2a	11.3a	***4.1b***	6.4a
Incorporated	Gloucester	2.50	29.6a	11.5a	***6.1a***	6.5a
No Lime	Orange	0	31.6a	10.9b	4.2b	4.9b
Surface	Orange	4.50	27.9ab	13.3a	4.7ab	5.5ab
Incorporated	Orange	4.50	31.9a	13.3a	4.9a	5.9a

*** Means within a column (for each soil type) with the same letter are not significantly different at the 5% level according to Student, Newman and Kuels test.**

Figure B.2. The height (cm) per day after seeding of the tall fescue for each liming treatment until 89 days after seeding. Data were shown for each soil type.





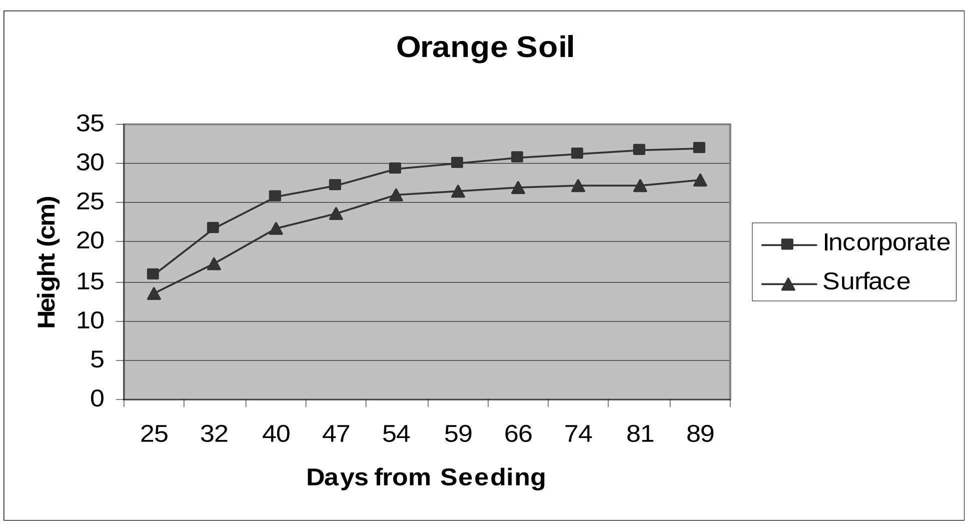
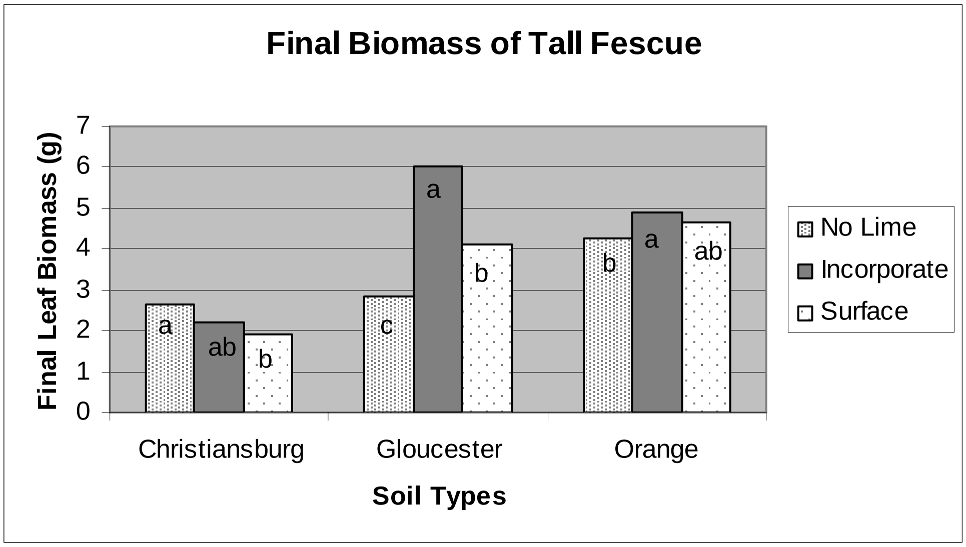


Figure B.1. The weight (grams) of the tall fescue for each liming treatment 89 days after seeding. The data is shown for each soil type. All lime treatments, within each soil type, with the same letter were not significantly different at the 5% level according to Student, Newman and Kuels test.



C. Comparing VDOT vs Soil Test Derived Rates of Phosphorus.

Objective: To evaluate the performance of tall fescue grown in soil that was amended with VDOT specified rate of P compared to the soil test derived rate of P.

Methods and Materials: In this greenhouse study, conducted beginning on April 18, 2005, tall fescue 'Jaguar II' seed was planted into native C-horizon Christiansburg, pH 5.4. The Christiansburg soil was high in clay and exchangeable aluminum (Table A.1).

Each quart size plastic pot was filled with 700g of dried soil. An unbleached coffee filter was placed on the inside of the pot (4" round) to retain the soil. Lab grade powdered lime (as $CaCO_3$) at the soil test derived rate (6.5 target soil pH) was incorporated into the soil of each pot on April 7. The pots were irrigated with water to field capacity, and allowed to dry for two days and then re-watered. Three wet/dry cycles were completed to initiate the lime and soil chemical reactions, thus raising the soil pH. Nitrogen at 90 lb/A was supplied to all pots with a surface application of Mesa™ (11.6% methylene urea + 5% other water insoluble N source) which provide 55% of N in a slowly available form. Potassium at 90 lb/A was also surface applied from K_2SO_4. Half of the pots received the standard VDOT 180 lb P_2O_5/A rate from $CaH_4(PO_4)_2$. The rest of the pots received a soil test dictated rate of P_2O_5 from $CaH_4(PO_4)_2$ (Table C.1). All fertilizers were applied on April 15th.

The seed (100 lb/A or 0.11g/pot) was applied to the surface of each pot on April 18th. The pots were watered daily with a fine mist to keep the seed from moving down the sides of the pot. When the roots were well-established, the pots were irrigated with drip irrigation two times daily, 1 minute per watering, to minimized leaching of fertilizer. The pots were arranged in a randomized block design. The two phosphorus treatments were replicated five times for each soil type. The plants were maintained for 131 days after sowing. Grass population per pot was evaluated for **height** about once a week, **clipping dry weight** (95)[3], and **re-growth height** 36 days after clipping (day 131).

Table C.1. Treatments and corresponding phosphorus that were applied to the soil surface at the time of seeding tall fescue. Soil test rate of P_2O_5 (200 lb/A) equals 1x rate.

Soil Type	**Treatment**	**P_2O_5 (lb/A)**
Christiansburg	No Phosphorus (P)	0
Christiansburg	0.5x	100
Christiansburg	VDOT Standard P	180
Christiansburg	1x	200
Christiansburg	1.5x	300
Christiansburg	2x	400

Results: The tall fescue height was similar at all P rates at 89 days after seeding, as well as after the plants were sheared (re-growth). However, the biomass for the treatments of the two highest levels of P_2O_5 (300 to 400 lb/A of P_2O_5) was significantly heavier than the lower rates. Biomass is an indicator of plant health, thus these two high rates of P would in theory produce more robust plants.

The recent development and implementation of the new Nutrient Management Plans for VDOT, which was effective on July 2006, will not allow a single application of P_2O_5 greater than 180 lb/A for any soil. This soil's P test was at a "L " level, and according to the new Nutrient Management Plans, a P_2O_5 application between 125-150 lbs/A is all that will be allowed for active construction and 90-100 lbs/A for roadside maintenance. These allowable rates are between the two lowest P_2O_5 treatment rates.

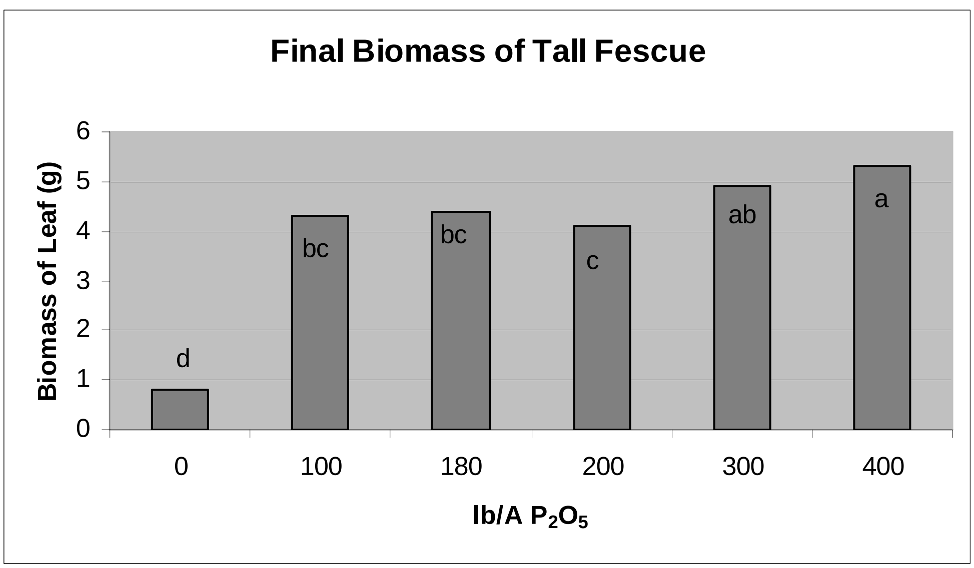
[3] Grass was cut at the soil surface. The grass recovered from this drastic clipping method, and the re-growth was measured.

Table C.2. Height and weight of grass at specific "Number of Days from Sowing".

Soil Type	P Treatment	P_2O_5 (lb/A)	Day 89 Height (cm)	Day 131 Re-growth height (cm)	Day 89 Biomass (g)
Christiansburg	No Phosphorus (P)	0	15.1b	3.9a	0.8d
Christiansburg	0.5x	100	34.9a	3.2a	4.3bc
Christiansburg	VDOT Standard P	180	32.4a	4.4a	4.4bc
Christiansburg	1x (Soil test P)	200	34.9a	4.0a	4.1c
Christiansburg	1.5x	300	32.9a	3.8a	4.9ab
Christiansburg	2x	400	34.4a	2.5a	5.3a

* Means within a column (for each measured variable) followed by the same letter are not significantly different at the 5% level according to Student, Newman and Kuels test.

Figure C.1. The weight (grams) of tall fescue for P application treatment 89 days after seeding in the Christiansburg soil. Treatments with the same letter were not significantly different at the 5% level according to Student, Newman and Kuels test.



D. Comparison of Tall Fescue Performance as affected by Three Rates of a 30% Slowly Available N Formulation.

Objective: To evaluate the performance of tall fescue grown in soil that was amended with various rates of 30% slowly released N in three soils from Virginia.

Methods and Materials: In this greenhouse study, initiated April 18, 2005, tall fescue 'Jaguar II' seed was planted into native C-horizon Christiansburg, Gloucester, and Orange soils with pH of 5.4, 5.0, and 4.4, respectively. The Christiansburg soil is clayey and high in exchangeable aluminum, the soil from Gloucester is a sandy loam, and the soil from Orange is high in clay and iron (very red) (Table A.1).

Each quart size plastic pot was filled with 700g of dried soil. An unbleached coffee filter was placed on the inside of the pot (4" round) to retain the soil. Lab grade powdered lime (as $CaCO_3$) at the soil test derived rate (6.5 target soil pH) was incorporated into the soil of each pot on April 7. The pots were irrigated with water to field capacity, and allowed to dry for two days and then re-watered. Three wet/dry cycles were completed to initiate the lime and soil chemical reactions, thus raising the soil pH.

Three N rates, 45, 60 and 90 lb/A, were surface applied to designated pots (Table D.1). The slowly released (SR) formulation of N was derived from 30% WIN from 15-30-15 (4.5% urea formaldehyde). Each pot received 180 lb P_2O_5/A and 90 lb K_2O/A, partially from the 15-30-15 fertilizer and/or from $CaH_4(PO_4)_2$, and from K_2SO_4. All fertilizers were applied on April 15th.

Table D.1. List of Nitrogen Treatments to Christiansburg soil.

Soil Type	N Amendments (lb N/A)
Christiansburg	0
Christiansburg	45
Christiansburg	60
Christiansburg	90
Gloucester	0
Gloucester	45
Gloucester	60
Gloucester	90
Orange	0
Orange	45
Orange	60
Orange	90

The seed (100 lb/A or 0.11g/pot) was applied to the surface of each pot on April 18th. The pots were watered daily with a fine mist to keep the seed from moving down the sides of the pot. When the roots were firmly planted, the pots were irrigated with drip irrigation two times daily, 1 minute per watering, to minimized leaching of fertilizer. The pots were arranged in a randomized block design. The three N treatments plus a control were replicated five times for each soil type. The plants were maintained for 131 days after sowing. Grass population per pot was evaluated for **height** about once a week, **clipping dry weight** (95)[4], and **re-growth height** 36 days after clipping (day 131).

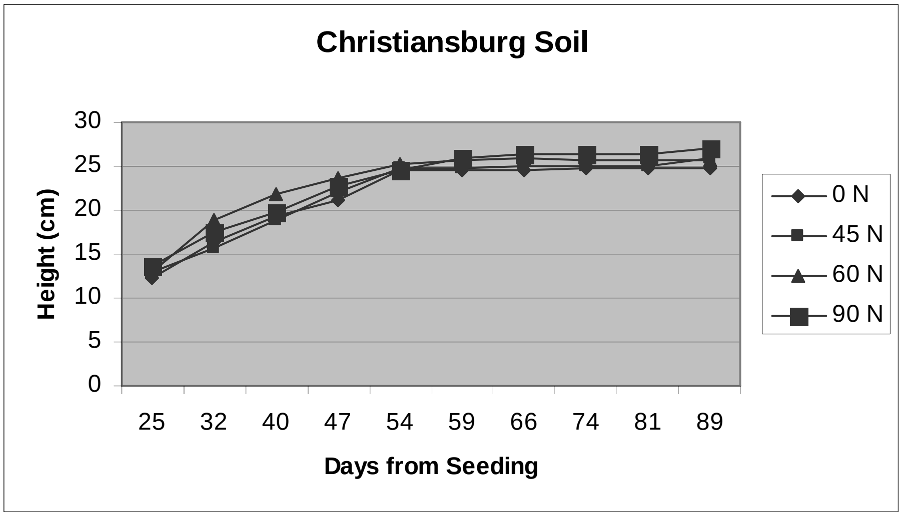
[4] Grass was cut at the soil surface. The grass recovered from this drastic clipping method, and the re-growth was measured.

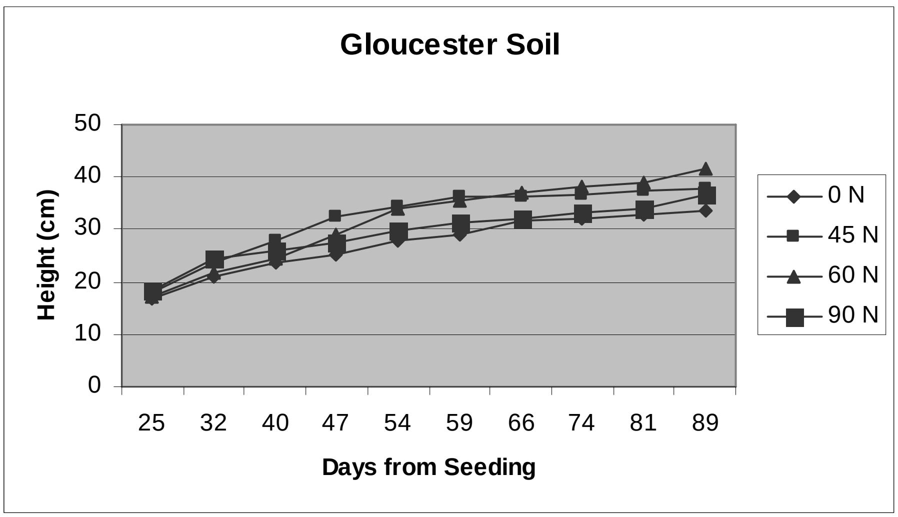
Results: Tall fescue height leveled off after 54 days in the Christiansburg and Orange soils, both were comprised of heavy clay (Figure D.1). In the sandier Gloucester soil, the plants continued to increase in size until the plants were clipped at 89 days. Height, charted over time, (Figure 1.4-1), especially for the Christiansburg and Orange soils, indicated that plants fertilized with 90 lb/N were the tallest over time.

After the grass was clipped the re-growth height was similar for all N treatments within each soil type (Table D.2). It is possible that by this time (131 days), the N was used or leached from the soil.

The most unexpected result encountered was that of the weights of the grasses grown in the Orange soil. By 89 days after seeding, all were not significantly different, including the control, which received no N (Figure D.2). Christiansburg-soil grown plants, were fertilized with 60 and 90 lb/A of N, had more biomass than the control and 45 lb/A treatment. The plants grown in the Gloucester soil and given 90 lb/A N were significantly heavier than all other treatments.

Figure D.1. The height (cm) per day after seeding of the tall fescue for each N treatment up to 89 days after seeding. Data shown for each soil type.





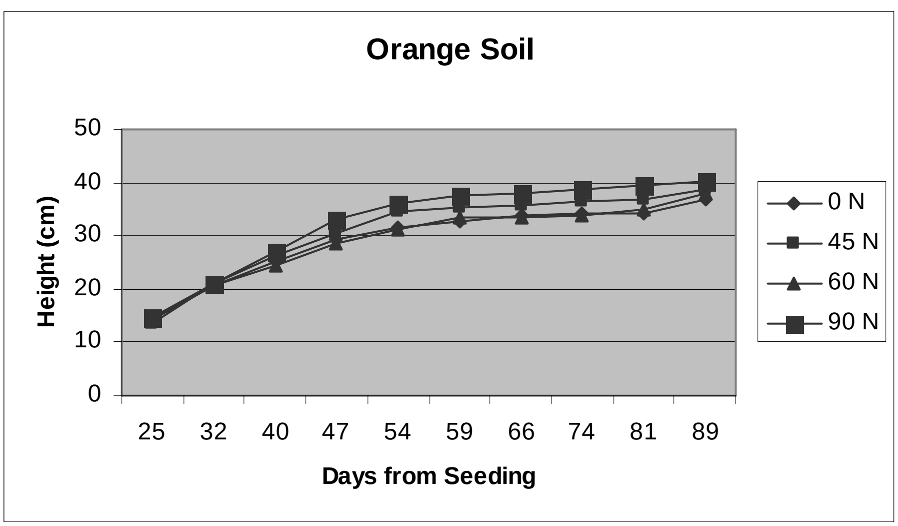
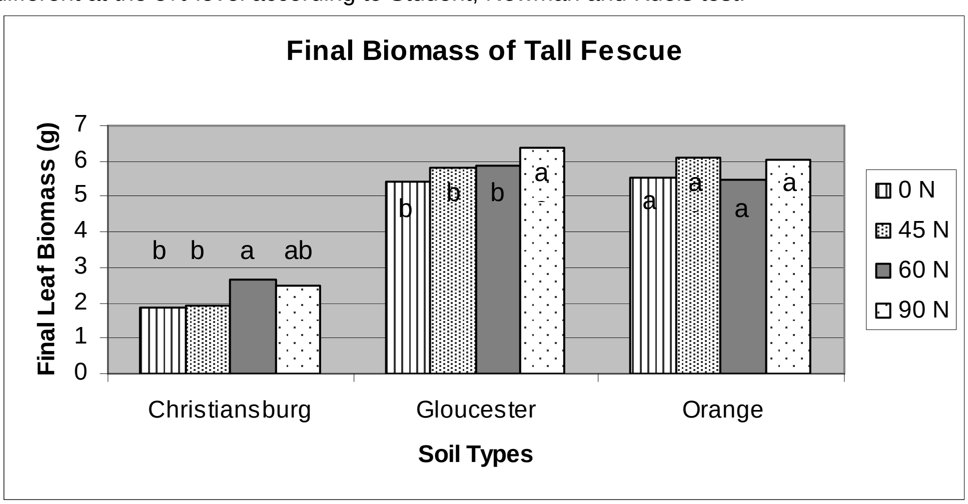


Table D.2. Height and weight of grass leaves at specific “Number of Days from Sowing”.

Soil Type	N (lb N/A)	Day 89 Height (cm)	Day 131 Re-growth Height (cm)	Weight on Day 89 (g)
Christiansburg	0	28.8a	6.0a	1.7b
Christiansburg	45	25.8a	5.7a	1.9b
Christiansburg	60	25.8a	6.1a	2.7a
Christiansburg	90	27.0a	5.8a	2.5ab
Gloucester	0	33.6b	12.2a	5.4b
Gloucester	45	37.6ab	12.4a	5.8b
Gloucester	60	41.5a	14.5a	5.8b
Gloucester	90	36.7ab	11.3a	6.4a
Orange	0	36.7a	12.0a	5.5a
Orange	45	38.5a	10.9a	6.1a
Orange	60	38.1a	11.8a	5.5a
Orange	90	40.2a	9.8a	6.1a

*** Means within a column (for each soil type) with the same letter are not significantly different at the 5% level according to Student, Newman and Kuels test.**

Figure D.2. The weight (grams) of the tall fescue for each N treatment 89 days after seeding. All N treatments effects (columns) by soil type, followed by the same letter were not significantly different at the 5% level according to Student, Newman and Kuels test.



2.3 Assessing manure-based compost on Virginia roadsides (pending funding from Water Quality Improvement Fund grant submitted to Virginia Department of Conservation and Recreation by Greg Evanylo (Virginia Tech faculty) in December, 2005)

No funding was awarded for this project.

Project 3 Consulting and Technology Transfer

3.1 VDOT Road and Bridge Specifications and Annual ESC/WM Program Response

Functioned as an available resource for inquiries by VDOT personnel related to areas of vegetation management expertise.

3.2 Roadside Soils and Turf Assimilative Capacity of Highway Runoff

Literature review was written assessing available research publications of the assimilative capacity of roadside soils and turf in relationship to capturing pollutants from highway runoff. It appears in its entirety below.

Retention of highway runoff pollutants by plants and soils as affected by Best Management Practices: A Literature Review

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Introduction

Runoff from roads and highways contains constituents that could threaten both surface water and groundwater quality if allowed to flow or leach into these receiving waters (Table 1). To prevent this, Best Management Practices (BMP's) can be implemented in design, installation, management, and maintenance of vegetated highway sites. BMP's are designed to reduce contaminant levels by either (Young et al., 1996):

- containing runoff until contaminants settle out or are adsorbed by soils (*structural* BMP's), or
- reducing initial concentrations (*non-structural* BMP's).

Successful implementation of BMP's, however, requires an understanding of the behavior of the potentially polluting constituents of highway runoff.

Potential pollutants in highway runoff

Overview

Potential pollutants in highway runoff can be divided into five major categories (Table 1):

- Solids: suspended and dissolved sediment
- Nutrients: nitrogen and phosphorus
- Metals: heavy metals and platinum group metals
- Compounds associated with de-icing salts: ionic salts and salt contaminants
- Organic compounds: mostly associated with gasoline and other vehicle fluids

The reactions of nutrients, metals, salts, and organic compounds in highway runoff with water and sediment are complex, and include dissolution, precipitation, ion exchange, adsorption, redox (oxidation/reduction), and complexation (Bricker, 2003). It is important to understand, however, that these processes, and thus the form of constituents in highway runoff, are affected by the activity and concentration of each runoff constituent (including sediment), and by site-specific rainfall, runoff water, and soil conditions.

Note: Solids, metals, nutrients, and other compounds are often reported as being in "*suspended*" or "*dissolved*" form. The accepted definition of a dissolved substance is one which can pass through a 0.45 micron filter (Eaton et al., 2005). In practice, solids in the "dissolved" fraction are still in particulate form, and nutrients and metals in the dissolved fraction are often adsorbed to sediment or organic matter, rather than being present in ionic form (Dean et al., 2005). With the advent of ultrafiltration, some researchers are using a 10 kDa (kilodalton) filter to separate dissolved metals (Tucillo, 2006), but, in this review, the 0.45 micron limit will be used to distinguish "dissolved" materials.

Table 1. Constituents of concern in highway runoff, and their sources. (Adapted from information given in U.S. EPA, 1993; Barrett et al., 1995; Granato, 1996; Thomson et al., 1997; Davis et al., 2001a; Beaton and Dudley, 2004; Huang et al., 2004; Ozaki et al., 2004; Ravindra et al., 2004; Venner et al., 2004.)

Constituent	Source
-------Solids-------	
Solids, including total suspended solids (TSS) and total dissolved solids (TDS)	Atmospheric deposition, solids transported by vehicles from other locations, sanding, pavement wear, vehicle part wear, roadside sediment disturbance.
-------Nutrients-------	
Nitrogen (N)	Atmospheric deposition, roadside fertilizer application, transported solids.
Phosphorus (P)	Atmospheric deposition, roadside fertilizer application, anti-rust agents in de-icing salts, transported solids.
-------Metals-------	
Cadmium (Cd)	Atmospheric deposition, tire wear, road marking paint.
Chromium (Cr)	Metal plating, moving engine parts, brake lining wear, impurities in de-icing salts.
Copper (Cu)	Atmospheric deposition, brake emissions, metal plating and engine part wear, some fungicides and insecticides.
Iron (Fe)	Auto body rust, brake linings, steel highway structures such as bridges and guardrails, engine parts.
Lead (Pb)	Atmospheric deposition, road marking paint, lead wheel weights, lubricating oil, bearing wear.
Manganese (Mn)	MMT (methlcyclopentyl manganese tricarbonyl) gasoline additive, engine part wear.
Nickel (Ni)	Diesel fuel and gasoline, lubricating oil, metal plating, bushing wear, brake lining wear and asphalt paving, impurities in de-icing salts.
Zinc (Zn)	Tire wear, atmospheric deposition, brake linings, exhaust emissions.
Platinum group metals (platinum, rhodium, palladium)	Catalytic converters.
-------Compounds associated with de-icing salts-------	
Sodium (Na), calcium (Ca), chloride (Cl) and magnesium, sulfate, potassium, fluoride, and others.	De-icing salts, impurities in de-icing salts, atmospheric deposition.
Sulfates	De-icing salts, roadway beds, fuel.
Cyanide	Anti-caking compounds in de-icing salts.
-------Organic Compounds-------	
Semi-volatile organic compounds (petroleum hydrocarbons, oil and grease, polycyclic aromatic hydrocarbons)	Crankcase oil, engine leaks, vehicle emissions, tire wear, asphalt pavement.
Volatile organic compounds [toluene, xylene, benzene, ethyl benzoate, MTBE (methyl tert-butyl ether)]	Atmospheric (in industrial areas), gasoline oxygenates, vehicle fluids.
Herbicides	Roadside maintenance activities.

Suspended and dissolved solids

Runoff of suspended and dissolved solids can cause water quality issues by impeding the light penetration necessary for plant growth, and by causing siltation, which destroys the habitat of aquatic organisms. However, many runoff pollutants are often associated with sediment, and BMP's that trap sediment will also trap a large percentage of these pollutants.

Runoff constituents that can be bound to either suspended or dissolved solids are:

- semi-volatile organic compounds such as polyaromatic hydrocarbons (PAH's) (Shinya et al., 2003)
- metals, such as zinc (Zn), lead (Pb), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), nickel (Ni) and cadmium (Cd) (Hewitt and Rashed, 1992; Sansalone and Buchberger, 1997a; Furumai et al., 2002; Shinya et al., 2003; Han et al., 2006)
- phosphorus (P) (Venner et al., 2004)

Asplund et al. (1982) found that total suspended solids (TSS) in Washington State highway runoff came from the following sources, in order of importance of contribution:

- sanding and de-icing: although seasonal, this contributes most of the TSS to runoff during the period it is used
- dust fall
- traffic: vehicles contribute TSS that are acquired elsewhere
- pavement deterioration (minor)

Nutrients (N and P)

Although nitrogen (N) and phosphorus (P) are essential nutrients for plant growth, they are also a major pollutant of U.S. surface waters (Carpenter et al., 1998). Excess N and P cause *eutrophication*, the over-enrichment of an ecological system with nutrients. This results in excess algal growth, reduced dissolved oxygen and water clarity, and subsequent lack of growth of aquatic plants and other organisms. Excess nitrate (NO_3^-) in water is also toxic to humans and animals, and impacts human and animal health (Carpenter et al., 1998; Evanylo and Beegle, 2006).

Much of the N in urban highway runoff in the eastern U.S. comes from wet and dry atmospheric deposition (USEPA, 2002). The source of this atmospheric N is nitrogen oxide (usually referred to as NO_x) emitted by vehicles, industrial and agricultural engines, and fuel combustion by electric utilities, and, to a lesser extent, nitrous oxide (N_2O) and ammonia (NH_3) volatilization resulting from farming operations (Puckett, 1994; USEPA, 2002). Wu et al. (1998) found that combined wet and dry deposition contributed 70-90% of the total N in urban highway runoff.

Roadside fertilizer application is another source of N in runoff (USEPA, 1993), especially if more fertilizer is applied than can be taken up by roadside vegetation, or if fertilizer is applied at a time of year when plant uptake of nutrients is slow (Mullins and Hansen, 2006). Both fertilizer N and N deposited by atmospheric deposition are easily transformed to ammonium (NH_4^+) and nitrate by biological processes in soil. Nitrate is the most mobile form of N in soils, and is highly susceptible to loss by leaching.

Atmospheric deposition is a source of P in runoff as well (USEPA, 1993), although atmospheric deposition of P is less than that of N (Jassby et al., 1994). Roadside fertilizer application also contributes P to highway runoff, as may the deposition from surrounding agricultural areas (Wu et al., 1998). While P is often sparingly soluble in soil, soluble P runoff may occur if roadside soils become saturated with P due to frequent fertilizer applications. Phosphorus bound to soil particles can be removed during runoff and subsequent erosion (Mullins and Hansen, 2006).

Metals

Heavy metals in highway runoff come from a number of different sources (Table 1). Most research on metals in highway runoff has focused on the heavy metals cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) (CH2MHill, 1998). All can be toxic to plants, animals, or humans if they are taken up or ingested in high concentrations, although Cu, Ni, and Zn are also essential at trace levels for plant growth. Manganese (Mn), also an essential trace element for plant growth, has become an element of concern since MMT replaced Pb as a gasoline anti-knocking element during the 1970's and 1980's (Brault et al., 1994; Lytle et al., 1994; Beaton and Dudley, 2004).

There has been recent research on the palladium group metals (platinum, palladium, and rhodium), which are deposited by catalytic converter degradation. The concentration of these palladium group metals in runoff has increased in the last few decades (Rhavindra et al., 2004), and elevated concentrations have been found in roadside soils (Ely et al., 2003; Sutherland, 2003), but the environmental consequences of this have not been quantified yet.

Although dissolved metals have the most detrimental effect on aquatic organisms (CH2MHill, 1998), research on the relative concentrations of dissolved and suspended metals in runoff has produced varying conclusions (Hewitt and Rashad, 1992; Sansalone and Buchberger, 1997b; Shinya et al., 2000; Furumai et al., 2002; Shinya et al., 2003; Han et al., 2006; and others). Apparently, the partitionment of metals in runoff is affected by factors such as rainfall pH, type of washoff (snow or rain), the presence or absence of other dissolved compounds that can bind the metals (Ca, Mg, organic matter), and type of roadway (Sansalone and Buchberger, 1996; Dean et al., 2005; Tucillo, 2006). For example, acidic rainwater will solubulize metals, but will be buffered to a neutral pH when it contacts cement pavement (Dean et al., 2005). In general, it appears that Cr, and Fe tend to be present mainly in particulate (> 0.45 micron) form, while Pb, Cd, Cu, Zn, and Ni may be found either in dissolved or particulate forms, depending on site conditions.

De-icing salts

De-icing salts such as sodium chloride (NaCl), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2$) are present in runoff in soluble, ionic form. The environmental effect of chloride de-icing salts have been summarized by Grueb et al. (1985), Granato (1996), Norrstrom and Jacks (1998), Novotny et al. (1998), Norrstrom and Bergstedt (2001), and Ramakrishna and Viraraghavan (2005) as:

- elevated, possibly toxic, salt levels in surface water and groundwater
- elevated sodium (Na) levels in soils, resulting in decreased soil permeability
- increased metal solubility in saline runoff, and in soils affected by salt runoff
- degradation of ferrocyanides (used as anti-caking agents) to toxic cyanides
- possibility of accumulation of trace impurities such as sulfate, bromide, vanadium, magnesium, fluoride, and strontium

Calcium magnesium acetate has been recommended as a more environmentally friendly de-icing chemical but more field studies need to be done to confirm this (Ramakrishna and Viraraghavan, 2005).

Obviously, the concentrations of de-icing salts in highway runoff, and subsequent environmental problems, are greater in areas with high snowfall and ice accumulation. Regions where the use of de-icing salts is more intermittent, however, may still have similar problems with runoff from highway salt storage facilities (Fitch et al., 2004), or in environmentally sensitive areas such as karst terrain where groundwater is directly affected by highway runoff (Donaldson, 2004).

Organic compounds

The most common organic contaminants in highway runoff are *semi-volatile organic compounds* (SVOC), such as petroleum hydrocarbons, oil and grease, and polyaromatic hydrocarbons. High concentrations of SVOC's can cause endocrine disruptions in aquatic and other, organisms (Lopes and Dionne, 2003).

Most SVOC's in highway runoff originate from crankcase oil leaks and vehicle emissions. SVOC's tend to be associated with both suspended and dissolved solids (Hewitt and Rashad, 1992; Shinya et al., 2000; Venner et al., 2004; Aryal et al., 2006).

Volatile organic compounds (VOC) are also present in runoff, and include toluene, xylenes, benzene, and ethyl benzene (also known as BTEX compounds). These derive from atmospheric deposition in industrial areas, and from some gasoline compounds. VOC's tend to volatilize, and the concentrations in runoff are generally too low to be toxic to aquatic organisms in surface waters. Drinking water derived from ground water contaminated with VOC's, however, could have chronic health effects in humans (Lopes and Dionne, 2003).

Methyl tert-butyl ether (MTBE), a gasoline oxygenate, is probably the VOC with the most negative environmental consequences, since it is less biodegradable than other VOC's (Delzer et al., 1996; Venner et al., 2004). Although MTBE has been detected in ground and surface waters, and in urban runoff (Moran et al., 2005), the exact source was unclear. To date, there has been little research on MTBE and other VOC's in highway runoff (Lopes and Dionne, 2003).

Factors that affect pollutant concentration in highway runoff

Average values

Highway runoff is a *non-point* source of pollutants, meaning that it does not derive from a single, continuous source (Carpenter et al., 1998). Thus, pollutant concentrations may be irregular, and will vary depending on a number of different, often site-specific, factors. Although "average" pollutant values that have been reported in studies by different researchers have been summarized by Driscoll et al. (1990a), Barrett et al. (1995), and other research, it can be difficult to compare these values because sampling and analysis methods differ (Granato, 2003). In an effort to catalog and validate these studies, the Federal Highway Administration's National Highway Runoff Water-Quality Data and Methodology Synthesis (NDAMS) project (Granato et al., 2003a; Granato et al., 2003b; Granato, 2003) has produced a searchable database of 2600 bibliographic entries, 1300 abstracts, and metadata for 262 research reports. This study also documented the technical issues inherent in monitoring highway runoff water quality, including sampling, sample-handling, and quality control.

First flush

The *first flush* effect has been documented by many researchers, and has been defined as being "the high pollutant load in the runoff water at the beginning of a rainfall event" (Shinya et al., 2003). A review of the literature by Kim et al. (2005) found that estimates for distinguishing the first flush of runoff from the rest of the runoff event range from 20% to 30% of the initial runoff volume. The level of pollutants in first flush runoff is usually affected by rainfall intensity and duration, and the length of the preceding dry period (Gupta and Saul, 1996), and the first flush effect appears to be more marked in areas with a high percentage of impervious cover (Young et al., 1996)

Although the existence of the first flush phenomena appears to be generally accepted, it has been debated by some researchers (Deletic and Maksimovic, 1998). Barrett et al. (1998a) did observe a first flush for many pollutants at the beginning of runoff events. However, they also found that most pollutants continued to run off through the duration of the rainfall event at the sites sampled, as vehicles continued to contribute pollutants throughout the event. They cautioned that constant pollutant input throughout a runoff event should be planned for in treatment systems.

A strong first flush does not occur with every runoff constituent, and the first flush concentrations of some runoff constituents vary depending on the specific study. It appears that site-specific factors also affect the concentration of pollutants in runoff first flush. For example, Sansalone and Buchberger (1997b) found that "dissolved" (< 0.45 micron) Zn, Cd, and Cu, showed a strong first flush effect, while Fe and Al did not. On the other hand, Shinya et al. (2003) found that total suspended solids, total P, and Fe were strongly concentrated in runoff first flush, apparently because approximately 50% of the total P and 92% of the total Fe were associated with TSS. In the same study, total N showed only a weak first flush effect because 80% was present in dissolved form. Han et al. (2006) also observed a strong first flush effect for TSS and for all particulate-bound metals except Pb, but also found that total N concentrations were relatively high in the first flush, possibly because N was sorbed to dissolved organic carbon.

Site-specific factors

The effect of any one site-specific factor on runoff pollutant concentration varies depending on location, time of year, and site characteristics. However, some site-specific factors that many researchers agree have an effect on the concentrations of at least one common runoff pollutant are:

- **Average daily traffic (ADT)**: While some researchers have found that ADT has a direct effect on runoff pollutant concentration (Irish et al., 1995), others have obtained contradictory results (Driscoll et al., 1990b; Barrett et al., 1995; Patel, 2005). Kayhanian et al. (2003) concluded that, although there was no direct correlation between ADT and level of runoff pollutants, ADT was one of a number of factors that, taken together, did influence pollutant concentration.

- **Surrounding land use** (for example, urban vs. rural sites): Driscoll et al. (1990b) found this to be one of the most important variables affecting runoff pollutant concentrations, with urban sites generally, although not always, having higher concentrations of pollutants than rural sites.

- **Permeability or perviousness of surrounding area:** This factor is related to land use, but also applies to runoff from highway structures such as bridge decks and impervious medians (Wu et al., 1998).

- **Number of antecedent dry days (or intensity of previous storm)**: Like average daily traffic, this factor may or may not have a direct effect on runoff pollutant concentration (Deletic and Maksimovic, 1998; Kayhanian et al., 2003; Venner et al., 2004), possibly because pollutants can be removed by wind, vehicles, or other means (Barrett et al., 1995; Patel, 2005).

- **Maximum rain volume, duration, and/or intensity**: (Driscoll et al., 1990b; Thomson et al., 1997; Deletic and Maksimovic, 1998; Kayhanian, 2003; Shinya et al., 2003).

- **Number of vehicles during storm**: Although Barrett et al. (1995) summarized research which found this to be a consistent factor in runoff load, it is also an extremely unpredictable factor.

- **Ratio of *pervious* to *impervious* material in a particular location:** This would include the presence of bridges and other large paved areas, or the presence or absence of roadside shoulders or medians (Deletic and Maksimovic, 1998; Wu et al., 1998).

Note that each of these factors, however, may not affect each runoff constituent at the same site in the same way, as demonstrated in Thomson et al.'s (1997) research in Washington State (Table 2).

Table 2. Identification of independent variables affecting constituent concentration in Washington State highway runoff during multiple regression analysis (adapted from Thomson et al., 1997 and Venner et al., 2004).

Constituent	Storm Duration	Storm Volume	Storm Intensity	Vehicles During Storm	Length of Antecedent Dry Period	Antecedent Traffic Count	Previous Storm Intensity
Fe		X	X		X		
TSS		X	X		X		X
Zn	X	X				X	X
P	X	X	X			X	
Nitrate		X	X			X	
Pb		X	X	X			X
Cu	X	X		X			
Oil and Grease		X		X			

Pollutant retention in vegetated BMP's: general principles

Introduction

As stated earlier, BMP's can be structural or non-structural. *Structural BMP's* are designed to control and confine highway runoff until pollutants settle out and infiltrate into the soil. These structures can be either vegetated or non-vegetated (Table 3). All vegetated BMP's are designed to remove pollutants by detaining runoff, filtration by vegetation, surface sedimentation, and infiltration into soil (Young et al., 1996). **If the BMP is not designed properly, however, there will be little pollutant retention because the *hydraulic residence time*, or the length of time runoff remains in the BMP, will be too short.**

Although specific details regarding the non-vegetated BMP's listed in Table 3 is beyond the scope of this review, the intended function of these structures is similar to that of vegetated BMP's, and many are combined with grass filter strips or buffer areas in runoff *treatment trains*, or series of BMP's for sequential runoff treatment. Detailed information on design of both vegetated and non-vegetated structural BMP's can be found in Schueler et al. (1992), Young et al. (1996), and Clar et al. (2004).

Non-structural BMP's are designed to remove pollutants at their source and include (Barrett et al., 1995; Young et al., 1996):

- planning of surrounding land use, including roadside landscaping.
- source control, such as controlled application of fertilizers (nutrient management) and pesticides to roadsides and medians, and controlled salt application.
- litter and debris control.
- control of highway structure maintenance activities such as bridge cleaning and painting.

Table 3. Types of structural BMP's used to control pollution from highway runoff (adapted from Young et al., 1996).

Vegetated BMP's	Non-vegetated BMP's
• Filter strips • Grassed swales • Infiltration basins • Constructed wetlands • Bioretention areas (small-scale BMP's for urban areas)	• Dry (detention) pond* • Wet ponds* • Infiltration trenches* • Sand filters** • Water quality inlets (oil and grit separators) • Porous pavement • Various small-scale non-vegetated filters used in urban areas.

* Usually surrounded by grass filter strips or other vegetation.

Pollutant retention by roadside plants

Although some uptake of metals and organic pollutants occurs in vegetated BMP's (Clar et al., 2004), the primary function of plants in BMP's appear to be (Maestri et al., 1988; Barrett et al., 1995; Piretz, 2001; Huang et al., 2004):

- soil stabilization
- decreasing runoff flow rate and increasing sedimentation and infiltration
- physical filtration of runoff
- nutrient uptake and transformation
- contributions made by root metabolism and organic matter to soil processes (including herbicide degradation)

There has been much recent research on phytoremediation, or the uptake and/or transformation of metals and other pollutants from contaminated soils by certain plant species. (For a detailed discussion of phytoremediation, see Appendix 1). This technique is still mainly experimental, and while it may be applicable to small, intensively managed, highly contaminated areas, it is unlikely to be effective in controlling metal levels in highway runoff.

Plants metabolize small amounts of metals from the soil as they grow, requiring low levels of Cu, Co (cobalt), Fe, Mo (molybdenum), Mn, Ni, and Zn as essential plant nutrients. Excess soil concentrations of most of these metals are generally either:

- rendered insoluble by soil chemical processes,
- or, if plant-available, are toxic to most plant species at very low concentrations.

This combination of low metal solubility/availability in soils, and the phytotoxic effect of high metal levels is known as the *soil-plant barrier* (Chaney and Giordano, 1977). It generally prevents toxic levels of trace elements from entering the food chain via consumption of plants by animals or humans. Some wetland plants have been shown to take up heavy metals such as Zn (Yu et al., 1995), presumably because metals are more available under reducing conditions. However, the amount of metal uptake in wetland plants is still limited by potential plant toxicity.

Pollutant retention by roadside soils

Nitrogen:

Nitrogen goes through more transformations in soil than any other plant nutrient (Mullins and Hansen, 2006). Plants take up N as either ammonium (NH_4^+) or nitrate (NO_3^-). Ammonium that is not taken up by plants can be *volatilized*, and nitrate can undergo *denitrification*: both processes resulting in a loss of N to the atmosphere as N_2 gas. Both ammonium and nitrate can be *immobilized*, or transformed into organic N forms that are unavailable to plants. Ammonium also undergoes biologically mediated *nitrification*, or transformation to nitrate. Nitrate that is not taken up by plants is very mobile and can easily be lost through leaching or runoff. These losses can be minimized by source control: adding less N to the soil and fertilizing at appropriate times of the year (Evanylo and Beegle, 2006). The leaching risk is greatest on sandy soils where N is applied at high rates at times when plant uptake is low (Mullins and Hansen, 2006).

Phosphorus:

In acid soils (pH <5.5), P tends to precipitate as Fe or aluminum (Al) phosphates, while in alkaline soils (pH >6.8), P precipitates as Ca phosphates (Mullins and Hansen, 2006). However, if the soil is saturated with P, excess P will be subject to leaching as dissolved reactive orthophosphate. This often happens in sandy soils because levels of native Fe and Al oxides are low, resulting in little P binding (Pierzynski and Gale, 2005.) The diffusion of P in the soil is limited, and it is only taken up by root hairs if it is located within ¼ inch of the root (Mullins and Hansen, 2006).

Loss of P from soil can be prevented by limiting the use of P fertilizers and organic amendments. The Virginia Phosphorus Index (Mullins et al., 2005) is a tool that is used to calculate the risk of P loss from roadside soils based on the amount of P applied plus erosion risk (sediment bound P loss), risk of runoff of dissolved reactive orthophosphate, and subsurface risk P leaching as dissolved reactive orthophosphate.

Heavy metals:

In soils, heavy metals are generally present in one of the following fractions (Brady and Weil, 2001):

- *Adsorbed or exchangeable (ionic)*: This fraction is relatively mobile, and is available for uptake by plants or for leaching, but is only a small portion of total soil metals.
- *Organic matter bound*: This fraction can be slowly released to plants with time as the organic matter decomposes.
- *Associated with carbonates or iron/manganese oxides*: These fractions are generally not plant-available unless soil pH becomes quite low.
- *Residual*: This fraction consists of sulfates and other insoluble compounds, and is the least plant-available.

Metals in soils can become more available if (Bartenhagen et al., 1995):

- Soil pH decreases, which increases hydrogen ions on exchange sites (displacing metals), and dissolves oxide and carbonate metal complexes.
- Soil redox potential decreases, resulting in less metal complexing.
- Soil salinity increases, causing competition for sites on the exchange complex.

After a review of the literature, Turer and Maynard (2003) concluded that it is generally accepted that heavy metals originating from highway runoff are higher in the upper part of the soil profile, and decrease with increasing distance from highway, indicating that most metals from highway runoff are not very mobile. They found that Cu, Pb, and Zn were enriched in the upper 6 inches of roadside soils in Cincinnati, OH and Corpus Christi, TX. These metals were relatively immobile and unlikely to be resolubulized because they were tightly bound to organic compounds which apparently originated from vehicle exhaust or asphalt pavement. Nickel and Cr in the roadside soils in these areas appeared to be native to the soil rather than originating from highway runoff.

Lee and Touray (1998) found that Mn and Cd were potentially most mobile in slightly acid solutions (such as acid rain). Zn was somewhat less mobile, and Pb and Fe had very limited mobility, possibly because they were in carbonate or iron oxide form. Dierkes and Geiger (1999) found that Cd and Zn were the most mobile metals in roadside embankments in Germany with high organic matter levels and near neutral pH. Approximately 20% of the Cd in these soils was present in plant-available form.

Salts:
Both sodium (Na) and calcium (Ca) dissolve from de-icing salts as cations, and will accumulate on the exchange complex of roadside soils. Excess Na in the soil may result in decreased permeability, (Novotny et al., 1998; Ramakrishna and Viraraghavan, 2005), but if salt is only applied occasionally, this effect is temporary. As stated above, metals such Pb, Cu, and Zn in roadside soils could be vulnerable to leaching if soils were subjected to high concentrations of de-icing salts, since both Na and Ca will displace metals from the exchange complex, and Na may cause dispersion of metal-organic and metal-oxide complexes (Norrstrom and Jacks, 1998). Again, this is unlikely to be a problem where de-icing salts are not used frequently (Ramakrishna and Viraraghavan, 2005).

PAH's and other organic compounds:
In soil, organic compounds can (Brady and Weil, 2001):

- *volatilize* into the atmosphere,
- be *adsorbed* and held in the soil by soil organic matter and clays,
- *leach* from the soil to ground or surface waters,
- be *decomposed* (biodegraded) by soil microorganisms, or
- be *taken up by plants or soil animals* (such as earthworms), and enter the food chain.

As stated earlier, VOC's in highway runoff tend to volatilize while SVOC's tend to be associated with both suspended and dissolved solids (Hewitt and Rashad, 1992; Shinya et al., 2000; Lopes and Dionne, 2003; Venner et al, 2004; Aryal et al., 2006). Research by Dierkes and Geiger (1999) in Germany on some SVOC's has demonstrated that PAH's will accumulate in the upper 4 inches of soils, because they adsorb strongly onto soil organic matter and clay and then do not biodegrade rapidly. Oil-type hydrocarbons (from leaks, etc.) are found mainly on soil surfaces near roads, and appear to mainly undergo volatilization and biodegradation before they enter the soil.

Note: Compost has been used by some states to control runoff and erosion on highway construction sites, and can be used as an alternative to commercial fertilizer to assist in the establishment of roadside vegetation. Glanville et al. (2004) examined the effect on water quality of composts used to control erosion from highway construction sites using three types of compost: biosolids compost, yard waste compost, and paper mill plus grain-processing waste composts. Although the runoff from composted areas had higher concentrations of heavy metals and nutrients than the runoff from non-amended sites, the total mass of these pollutants in runoff from non-amended areas was much higher because far more runoff and erosion occurred in these areas.

Pollutant retention in vegetated BMP's: specific structures

Filter strips

Filter strips are ideally flat or gently sloping areas that are densely vegetated with grass, shrubs or trees, and are probably the least expensive structural BMP's to build and maintain (Young et al., 1996). Filter strips are designed to handle overland sheet flow rather than directed flows, and work best in areas that do not receive high velocity runoff flows (Barrett et al., 1995). Although some researchers have recommended that filter strips have a slope of no greater than 9-12% (Walsh et al., 1997), existing road shoulders with slopes greater than this can be used as filter strips if width is increased to allow for increased slope, and if vegetative cover is maintained (Kearfott et al., 2005; Barrett et al., 2006).

Filter strips can remove substantial amounts of suspended solids and associated metals if correctly designed, but do not generally provide good nutrient removal, and can even add nutrients to runoff because of contributions from roadside fertilizer application and decomposing vegetation (Table 4; also Gannon et al., 1995; Barrett et al., 2006). Maintaining dense vegetation is important, because removal efficiencies are considerably reduced if vegetative cover is less than 80% and maximum pollutant removal is achieved if cover is 90% or more (Kearfott et al., 2005; Barrett et al., 2006). Filter strip efficiency is also dependent on width, slope, soil permeability, runoff velocity, and size of contributing runoff area (Young et al., 1996).

Note: The performance of runoff treatment BMP's is usually expressed as *percent removal* of a specific pollutant. Venner et al. (2004) and Barrett (2005) have pointed out that this may not be an accurate method of measuring BMP efficiency, since percent removal of a specific pollutant tends to be lower if influent concentration of that pollutant is low. Since most of the literature uses percent removal to quantify BMP performance, however, the term will be used in this review.

Table 4. Pollutant removal efficiencies for filter strips in Texas. (Note: numbers in parentheses show “negative removal” where the filter strip itself added the pollutant to the runoff.) nd=not determined.

Filter strip study reference	TSS	Total N	NO_3^--N	Total P	Cu	Pb	Zn
	% removal						
2 strips, TX (Walsh et al., 1997; Barrett et al., 1997)	85-87	33-44	23-50	34-44	nd	17-41	75-91
3 strips, TX (Kearfott et al., 2005)	73-89	(-154) - 19*	(-132) - 6*	(-250) - (-90)	75-90	84-95	**

*In some locations, total N, nitrate-N, and total P were generally higher after runoff traveled through the filter strip, and were likely contributed by either roadside fertilizer and/or decomposing vegetation.
** Zn leached from the collecting apparatus in this study, causing elevated total and dissolved Zn concentrations in runoff.

Grassed swales

Grassed swales are similar to filter strips but are constructed with a shallow channel to hold runoff, thus can also convey flows. Ideally, grassed swales should have slopes <3-6% and a length greater than 200-250 feet (Schueler et al., 1992; Yu et al., 2001). Grassed swales must be maintained by mowing and periodic sediment removal (Finley and Young, 1993; CH2MHill, 1998).

Hydraulic residence time and swale soil infiltration rate may be the most important factors affecting pollutant removal efficiency in swales (Yousef et al., 1985; Barrett et al., 1997; CH2MHill, 1998). Infiltration rate can be increased by selecting proper soil for swale construction, and by avoiding soil compaction during construction. To increase hydraulic residence time, check dams within the swale are highly recommended (Yu et al., 1995; Kaighn and Yu, 1996).

Both Yu et al. (2001) and Mazer et al. (2001) noted that swales tended not to reduce pollutants if inflow rate of runoff is too high (as in strong storms). Sediment and associated pollutants within the swale can be re-suspended and lost if the swale is inundated with water. Mazer et al. (2001) recommended that estimated *hydraulic loading rate*, as determined by flow rate and treatment area, be used as a predictor of swale performance.

Swales can remove a high percentage of total suspended solids and associated metals if they are properly designed. A review of the literature (CH2MHill, 1998), showed that metal removal percentages in swales was quite variable. Swales surveyed in the review removed from 14 to 67 % of total runoff Cu, 4 to 90% of total Zn, and 15 to 99% of total Pb. The removal of metals in swales was shown to depend highly on factors which affected hydraulic residence time, including the slope ratio, density of vegetative cover, high infiltration rate of underlying soil, the length of swale, and the presence or absence of check dams. Barrett et al. (1997) and CH2MHill (1998) have recommended at least a 9 minute hydraulic residence time.

Nutrient removal in swales can be quite low, especially for nitrogen. Both

Yousef et al. (1985) and Barrett et al. (1997) found that the swale actually added nitrogen removal to the runoff, apparently because dead and decomposing vegetation on the swale contributed nitrate to the drainage water. Other swales have been shown to remove at least some N and P (Barrett et al., 1998b; Yu et al., 2001), but in general, source control of these nutrients may be a better way of reducing their concentrations in highway runoff.

Infiltration basins

An infiltration basin is a "surface pond which captures the first flush of stormwater and treats it by allowing it to percolate into the ground and through permeable soils" (Young et al., 1996). Generally, infiltration basins are designed to hold the first ½ inch of rainfall associated with the first flush (Barrett et al., 1995). Infiltration basins treat runoff pollutants by sedimentation, adsorption onto soil particles, and by biological degradation (decomposition and plant uptake of nutrients), and can be quite efficient in pollutant removal (Table 5). Most of these structures fail within 5 years, however, because they are clogged by fine sediments, and then must be altered so they function as wet ponds or wetlands (Schueler et al., 1992). Because of the high reported failure rate and high cost, infiltration basins tend not to be a good option for a vegetated BMP (CH2MHill, 1998).

Table 5. Specific pollutant removal estimates for infiltration basins (adapted from data presented in Young et al., 1996.)

Type of infiltration basin	Total suspended solids (TSS)	Total N	Total P	Heavy metals
	-------------------% removal		--------------------	
Basin designed to store 0.5" runoff per acre	75	45-55	50-55	75-80
Basin designed to store 1" runoff per acre	90	55-60	60-70	85-90

Constructed wetlands

Constructed wetlands specifically designed for highway runoff treat pollutants by settling, soil filtration, decomposition, plant uptake (especially of nutrients), and other processes (Table 6). Unlike wetland mitigation sites, wetlands for runoff treatment do not have to be designed to provide all wetland ecosystems functions (Barrett et al., 1995). The water table in the wetland should be at or near the surface, the soils should have low permeability, and the wetland should be designed so that runoff retention time is approximately 6 to 14 days (Schueler et al., 1992; Barrett et al., 1995; Young et al., 1996). Wetland construction is relatively expensive, and wetlands require intensive maintenance for the first three years after construction. Wetlands may not function as effectively in winter when vegetation is dormant and soil processes are slowed (Gannon et al., 1995).

Constructed wetlands have been shown to be quite effective at reducing levels of TSS, N, P, metals, and organic compounds in runoff **if runoff retention time is long enough to allow wetland soil processes to take place** (Gannon et al., 1995; DeBusk, 1999; Shutes et al., 2001; Farrell and Scheckenberger, 2003). Birch et al. (2004) found relatively low and considerably variable pollutant removal efficiencies for TSS, N, P, and other pollutants in a constructed wetland in Australia and concluded that the runoff detention time was too short. The wetland was too small for the size of the catchment area, especially during storms. Shutes et al. (2001) and Revitt et al. (2004) found that properly designed wetlands receiving highway runoff removed most pollutants during large storms.

Yu et al. (1998a, 1998b) examined artificial wetlands in Virginia that were constructed to meet wetland mitigation requirements in order to determine if they could also serve as highway runoff treatment BMP's. Most sites removed relatively large percentages of TSS, P, orthophosphate, and Zn from highway runoff without appearing to decrease wetland ecological function. Removal rates were increased in wetlands where design maximized hydraulic residence time.

Some plant uptake of soluble metals, particularly Zn, by certain plant species such as *Typha latifolia* (cattail) and *Phragmites australis* (common reed) may occur in wetlands receiving highway runoff (Ellis et al., 1994, Mungur et al., 1995; Yu et al., 1995; CH2MHill, 1998; Shutes et al., 2001). Although this plant uptake may reduce soil levels of metals, it increases levels in plant vegetation. Decomposing vegetation will then release accumulated metals into sediment (Mungur et al., 1995) unless the plant material is harvested.

For example, Shutes et al. (2001) found that one constructed wetland they studied actually released Cu during high flow runoff events, presumably because Cu was released from decomposing vegetation.

Overall, it appears that properly designed and constructed wetlands can remove relatively high rates of contaminants from highway runoff. Further research, however, is needed to quantify the performance of these wetlands with time, since changes in sediment depth, sediment concentration of metals and salts, accumulation of organic matter, and possible re-suspension of contaminants, may occur as the wetland ages (Pontier et al., 2004).

Table 6. Pollutant removal mechanisms in constructed wetlands (Gannon et al., 1995; DeBusk, 1999).

Pollutant	Removal process
Total suspended solids (TSS)	Sedimentation
Total P	Sedimentation; adsorption; complexation as Ca or Fe/Al phosphates; plant uptake
Total N	Denitrification of NO_3^-; adsorption and volatilization of NH_4^-; plant uptake
Metals	Sedimentation; adsorption; complexation with carbonates, Fe/Al oxides, and organic matter; precipitation with sulfides; some plant uptake
Oil and grease	Degradation by light; microbial decomposition; some volatilization
Volatile organic compounds (VOC)	Volatilization

Bioretention areas

A bioretention area is a small BMP structure that uses both woody and herbaceous plants with layered substrate materials such as mulch, organic matter, and/or soil and sand to provide runoff treatment for space-limited urban areas, such as parking lots and median strips, where other BMP's might be inappropriate (Davis et al., 2001b; Davis et al., 2003). The prototypical bioretention area design was developed in the 1990's by the Prince Georges County, Maryland Department of Environmental Resources. In this design, runoff flows from an impervious surface over a sand trench to a planting area consisting of mulch over soil over a sand trench. The planting area is designed to hold 6 inches of ponded runoff so that it can slowly infiltrate into the organic materials and soil below (USEPA, 1998). The design can be modified to include gravel and/or underdrains.

Bioretention areas have been shown to provide removal of suspended and dissolved heavy metals (Davis et al., 2003) and TSS and associated pollutants, especially for small storms (Yu and Stopinski, 2001). Removal percentages for organic N and total P were also relatively high, but nitrate removal percentages were low, since N build-up in the bioretention area tends to surpass vegetative uptake (Davis et al., 2003).

Accumulation of metals in BMP's

If vegetated BMP's are designed so they are efficient at trapping high percentages of metals, there is a possibility that metals may accumulate to potentially toxic levels in the BMP soils. Walsh et al. (1997) and Barrett et al. (1997) used the U.S. Standards for the Use or Disposal of Sewage Sludge (Title 40 of the Code of Federal Regulations, Part 503; also known as the "Part 503 rule") to evaluate annual and cumulative Pb and Zn loadings in filter strips in Texas, and found that annual loading rates were less than a tenth of those permitted by the Part 503 rule. They estimated that it would take 200 years before these metals reached the cumulative loading rate limits mandated in the Part 503 rule.

Wigington et al. (1986) measured heavy metals in swales in suburban Fairfax County, VA, and found that, although metals did accumulate in the top 5 cm (2 inches) of swale soils, the pattern of accumulation was similar to that seen in roadside soils, and no subsurface metal enrichment attributable to runoff was found. Soils examined were relatively fine-textured, however, with low infiltration rates.

Yousef et al. (1994) measured heavy metals in the bottom sediments of Florida detention ponds (non-vegetated) receiving highway runoff, and determined that most of the metals were tightly bound to the sediments and would not be prone to leaching into groundwater. Toxicity characteristic leaching procedures (TCLP) performed on the sediments revealed that they were not hazardous wastes. They recommended cleaning out detention ponds at intervals of 25 years to reduce the potential for groundwater contamination.

It appears, based on estimates of metal accumulation with time, that BMP's that receive highway runoff will tend not to accumulate toxic levels of heavy metals. However, this issue will require further on-site research as existing BMP's become older.

Summary and conclusions

- Primary constituents of concern in highway runoff are suspended and dissolved solids, nitrogen (N), phosphorus (P), heavy metals, de-icing salts, semi-volatile organic compounds (SVOC), and volatile organic compounds (VOC).

- In general, metals, SVOC's and some P in highway runoff tend to be associated with suspended sediments; thus Best Management Practices (BMP's) that are designed to trap suspended sediments will provide reasonably good removal of these contaminants.

- The functions of plants in vegetated BMP's are mainly soil stabilization, decreasing runoff flow rate, increasing sedimentation and infiltration, physical filtration of runoff, nutrient uptake and transformation, and the contribution of root metabolism and organic matter to soil processes. While some metal uptake occurs (particularly in wetland species), this is limited by the soil-plant barrier.

- Soils in vegetated BMP's retain and transform pollutants in many ways, although this is dependent on soil pH, soil texture, and other chemical and physical soil properties.

- Filter strips and grassed swales have been shown to remove total suspended solids (TSS) and associated metals if properly designed, but generally do not provide good removal of nutrients. Source control is recommended to reduce nutrient levels in highway runoff.

- Infiltration basins have relatively high pollutant removal efficiencies but are expensive and clog easily. Constructed wetlands are a better alternative. Wetlands generally provide adequate removal of most pollutants, but further research is needed to quantify the sustained performance of constructed wetlands as a runoff treatment with time.

- Small scale bioretention areas appear to work as BMP's in urban areas, but can be expensive and maintenance-intensive.

- Vegetative BMP's receiving highway runoff do not appear to retain toxic levels of metals over time.

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Appendix: Phytoremediation of pollutants

Introduction

Phytoremediation has been defined as "the use of plants to partially or substantially remediate selected contaminants in soil, sludge, sediment, groundwater, surface water, and waste water" (Pivetz, 2001). At present, phytoremediation is largely an experimental technique. Although laboratory and field studies have shown positive results, various phytoremediation techniques are still being refined (Trapp and Karlson, 2001). The term phytoremediation encompasses several different techniques, which are summarized below.

Phytoextraction

Plants that grow naturally on soils that contain high levels of metals have developed evolutionary responses to deal with potentially phytotoxic metal concentrations (Baker, 1981). *Accumulators* or *hyper-accumulators* are able to take up levels of metals that would be toxic to other plants. For example, some species in the plant genus *Thlapsi* have been shown to be Zn and Cd hyper-accumulators and some species in the genus *Alyssum* will hyper-accumulate Ni and Co (Angle et al., 2003). *Excluders* have developed physiological mechanisms that prevent metal translocation from roots to above-ground plant tissue.

Species of plants that are metal hyper-accumulators have been used experimentally to remove metals from soil in a technique known as *phytoextraction* (Salt et al., 1995; Dzantor and Beauchamp, 2002; Lasat, 2002), but there are still questions that need to be answered about this technique. It may be a viable method for slowly extracting metals from soils with high metal levels, but careful management is necessary. For example, since only a small percentage of total soil metals are available for plant uptake, it may necessary to treat the soil with chelating agents (DTPA-TEA, EDTA, organic chelators, etc.) or other agents to increase metal bioavailability (Barter, 1999; Lasat, 2002). The total biomass produced by hyperaccumulator plants is generally low, so remediation may take a number of years (Beauchamp and Dzantor, 2002). Hyperaccumulator plants must be harvested and disposed of properly, and site access must be restricted to animals and humans during the growing season, in order to prevent metals from entering the food chain (UNEP, 2003).

Phyto-stabilization

In phytostabilization, metal-tolerant plant species are used to revegetate soils with toxic levels of heavy metals. This results in the immobilization of metals by root absorption and adsorption or precipitation in the root zone (Barter, 1999), and also helps prevent erosion of contaminated soil (Salt et al., 1995). Plants used for this technique should ideally be metal excluders so that above-ground portions do not become toxic. More research is required on this method of phytoremediation before it becomes a feasible option (Dzantor and Beauchamp, 2002).

Rhizofiltration

Rhizofiltration involves the use of plant roots to absorb and precipitate pollutants from effluents (Salt et al., 1995). Rhizofiltration is used for contaminants that are in solution in water, and has been used experimentally to remove radionuclides from ponds (Barter, 1999). Hydroponically grown plants have also been shown to remove heavy metals from water (Raskin et al., 1997). Again, plants are harvested and removed when root metal levels become high (Barter, 1999).

Remediation of organic compounds

There are several methods that have been used to phytoremediate organic compounds: phytodegradation, rhizodegradation, phytovolatilization (Pivetz, 2001). The basic principle, however, is that certain plant species are able to break down organic compounds in contaminated soils by metabolic processes, either in the shoots or roots; or by increasing microbial activity in the rhizosphere (Salt et al., 1995; Barter, 1999; Dzantor and Beauchamp, 2002.) These methods have been used experimentally to remove herbicides, VOC's, PAH's, PCB's, and other contaminants from soil (Beauchamp and Dzantor, 2002), but are still being refined.

Project 4 Extension and Vegetation Management Training

4.1 Roadside Vegetation Management Training

VT personnel are prepared to provide training to personnel or VDOT clientele upon request by Asset Management.

4.2 VDOT Roadside Manager Series: Roadside Grasses, Companion Plants, and Legumes – Volume 3 ("The Roadside Vegetation Manual")

The Roadside Vegetation Manual has been submitted to VDOT for review, as specified in the 2006 contract.

4.3 VDOT Nutrient Management Training

Assisted and consulted with Lee Daniels on appropriate topics in developing and administering training materials specific to VDOT nutrient management needs.

4.4 Developing and implementing cooperative research and education components with the VT Weed Management team that contracts with VDOT.

Currently working with the Weed Management team on website development and improvement ideas, as well as developing weed control investigations related to vegetation establishment.

4.5 Miscellaneous services provided by the VT Agronomic Research Team

Members of the Vegetation Management team were in attendance at quarterly meetings to present current information and provide expertise in discussions related to vegetation establishment and management.

Project 5 Project Management and Website Reporting

5.1 VT Website – Virginia Roadside Management Research, Final Reports

Website has been updated with research results, literature reviews, and information pertinent to VDOT needs throughout the 2006 season. The website is currently undergoing an organizational restructuring in a collaborative effort with the VT Weed Management group.

Appendix A

Proposed Mowing Guidelines and Rationale for Virginia Roadsides

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Mowing cool season turfgrasses [fescues, bluegrasses]
Mowing highway corridors is an expensive operation requiring special mechanical equipment, labor, and fuel. Mowing along highways subjects personnel and motorists to higher risks of accidents. Thus, a minimum mowing schedule will reduce traffic hazards, labor, repairs, equipment, and fuel costs. Vegetation that obstructs views for the safety of motorists, as along certain medians and interchanges, must be mowed; however, it should not be necessary to mow more often than <u>one to three times yearly</u> by following the guidelines and principles outlined below.

The primary grasses used in medians and shoulders by VDOT are cool-season grasses such as tall fescue and the fine-leaf fescues (Hard, Chewings, and Creeping Red), with Kentucky bluegrass being a very minor component. These grasses thrive during cooler periods and develop seedheads only once yearly during the spring season. Once-a-year seedhead development occurs because there are two distinct requirements: 1) short days with cold temperatures during the fall-winter season induct special buds capable of forming stems with seedheads, and 2) the inducted buds develop into seedheads the next spring in response to warming temperatures and longer days. All tillers (or shoots) with inducted buds die after seedhead maturity; they also die when mowed below the inducted seedhead. This is not bad; it is a natural process that should be allowed to run its course.

Mowing just below these developed (or developing) seedheads is the <u>primary goal of the first spring mowing.</u> Why? The plant is genetically programmed to develop seedheads each spring and so it is directing much of its energy towards this and not to vegetative shoot production. If mowing occurs too early and only removes half or less of the developing seedhead, then the plant keeps directing its energy to re-grow the seedhead. Waiting to mow until just after the boot stage (when the seedhead is still enclosed in the stem) as the seedhead begins to emerge, should effectively remove the whole seedhead.

At this point, these reproductive tillers die and stored energy is then <u>released</u> and directed towards production of vegetative (leafy) tillers. The resulting re-growth consists almost entirely of “leafy” plants that increase in density and provide a shorter, more groomed, appearance. Proper spring mowing results in turf density that suppresses weeds.
Research has shown that the ideal mowing height for roadside cool season grasses is 4 to 6 inches. Lower mowing heights remove too much of the leaf area and reduces the plant’s ability to photosynthesize, maintain density, and provide adequate energy for a robust root system. Severe mowing events that scalp the turf (going from 10 or 12 inches to 2 inches, rather than 4-6) shock the plants, often leading to root death and stand thinning.

Bottom line: Do not mow cool season grasses lower that 4 inches on the roadside and avoid summer mowings to already heat or drought-stressed plants.

<u>Additional mowings may be needed to control and prevent the spread of tall, unsightly weeds along the roadsides or because of line-of sight issues.</u>

VDOT-sponsored mowing research at the Turfgrass Research Center in Blacksburg conducted over a five-year period indicated no significant difference in tall fescue or fine fescue percent ground cover between mowing at a 4-inch height once in the spring, mowing spring + fall, or mowing spring + summer + fall. The plots that were never mowed showed a much higher weed infestation than those that were mowed.

Bottom line: Mowing at least once a year following seedhead emergence increases turf density and lowers weed infestation.

Setting Spring Mowing Schedules for Cool Season Grasses Based on Growing Degree Days

For many cool-season plants temperature and light signals the timing of reproductive growth; a common measure agronomists use to predict growth stages are growing degree days [GDD]. GDD are the accumulation of average daily temperatures above a certain baseline temperature. **The chart uses 50 ^{o}F as a baseline and 30 to 50 year average weather data to determine the dates when enough GDD have been accumulated for the boot stage to be occurring (= 400 GDD) and total seedhead emergence to have occurred (= 600 GDD).** Our estimate is that tall fescue will have reached the boot stage by 400 GDD and completely headed-out (flowered) by the time 600 GDD have been reached in each District. **<u>Mowing should not begin until fescue has reached the boot stage, but should be completed in each District by the time complete flowering [seedhead emergence] has occurred.</u>** This is the basis for the suggested beginning and ending mowing dates listed in the table above. Our GDD ranges are based on 30 to 50 year averages from weather stations located near each District Office. These data can be accessed at: http://www.dnr.state.sc.us/climate/sercc/climateinfo/historical/historical_va.html

Boot stage is when the reproductive tillers can be cut open and the immature seedhead can be found. The next stage [emergence] is the seedhead starting to come out of the tiller and the final stage is the seedhead fully emerged.

Mowing warm season turfgrasses [bermudagrass, zoysiagrass]

Warm-season grasses have more prostrate (or horizontal) growth habits and can be safely mowed at a height of 2 to 3 inches, if the terrain is smooth enough to prevent scalping. On the Coastal Plain they will green-up in April, but will not put on enough vertical growth to require mowing until late May or June. Mowing prior to this may mostly be for cutting down unsightly cool-season weeds. Bermudagrass will produce seedheads throughout the summer growing season, but they do not often extend much above the turf canopy, nor are they a large energy-drain concern as with the fescues. Mowing once or twice per summer season may be all that is required for weed control and aesthetics.

VDOT Roadside Turf Mowing Schedule by District – Cool Season Grasses

This chart lists the approximate dates for mowing of cool season grasses. The timing of the first mowing is the key to the mowing maintenance program. The subsequent mowings control herbaceous and woody growth or are needed for line-of-sight issues.

District	Office	Mowing Height Range	GDD range*	First Mowing [control grass growth]		Second Mowing [control herbaceous weeds]	Third Mowing [control woody growth]
				begin	end		
1	Bristol	4” to 6”	400-600	May 10	June 10	late July to late Aug	mid Sept to late Oct
2	Salem	4” to 6”	400-600	May 5	June 5	late July to late Aug	mid Sept to late Oct
3	Lynchburg	4” to 6”	400-600	May 5	June 5	late July to late Aug	mid Sept to late Oct
4	Richmond	4” to 6”	400-600	May 1	June 1	late July to early Aug	mid Sept to late Oct
5	Hampton Roads	4” to 6”	400-600	April 20	May 20	early July to early Aug	late Sept to late Oct
6	Fredericksburg	4” to 6”	400-600	May 5	June 5	late July to late Aug	mid Sept to late Oct
7	Culpeper	4” to 6”	400-600	May 5	June 5	late July to late Aug	mid Sept to late Oct
8	Staunton	4” to 6”	400-600	May 10	June 10	late July to late Aug	mid Sept to late Oct
9	N. Virginia	4” to 6”	400-600	May 5	June 5	late July to late Aug	mid Sept to late Oct

*****GDD = Growing Degree Days with a base temperature of 50 ^{o}F.

GDD = Average daily temperature minus 50 ^{o}F beginning Jan 1. If the GDD total for a certain day is not > 0 it is not counted towards the cumulative sum of GDD.

VDOT Roadside Turf Mowing Schedule by District – Warm Season Grasses

This chart lists the approximate dates for mowing of Warm Season grasses. Mowing will continue throughout the growing season at approximately every 3-4 weeks. Some areas may require more frequent mowings to control herbaceous and woody growth or are needed for line-of-sight issues.

District	**Office**	**Mowing Height Range**	**Mowing Dates [Approx.]**		
			first	**last**	
4	Richmond	2” to 4”	May25	Aug 30	Bermudagrass, Zoysiagrass, Centipedegrass will continue to grow steadily throughout the warm months of summer and go dormant [requires no mowing] from late Sept until May
5	Hampton Roads	2” to 4”	May 10	Sept 20	
6	Fredericksburg	2” to 4”	June 5	Aug 30	
9	N. Virginia	2” to 4”	June 5	Aug 30	

VDOT Roadside Turf Mowing Schedule – Legumes, Wildflowers and Native Grasses

This chart lists the approximate dates for mowing of wildflower and native grasses. Subsequent mowings to control herbaceous and woody growth or for line-of-sight issues may be needed.

		Mowing Height Range	**Mowing Dates [Approx.]**		
Legumes	Lespedeza, crown vetch, flat pea	> 8"	Mid July	Mid Sept	Legumes are generally planted in areas where no mowing occurs. Mowing more than twice per year without a 60 day rest period between will greatly reduce or destroy the legumes.
Wildflowers	Many species	4" to 6"		Oct 15	Mow only after blooms have dried and to clean up area in late fall
Tall Native grasses	Switchgrass, Indiangrass, Big Bluestem	6" to 12"	Mid April	Or Oct 15	Theses species should NEVER be planted where line of sight is an important factor. The best time to mow these species is in early spring and the second best time is in late fall
Short Native grasses	Blue grama buffalograss	6" to 8"	Mid April	Or Oct 15	These plants will not exceed 15 inches in height and may not need to be mowed. They could be mowed in the late fall to reduce the amount of dry top growth.

Mowing prior to prescribed times may be used to cut down unsightly cool-season weeds. The weed control mowing may take place in early June with a minimum cutting height of 8 inches.

The native grasses are warm season species that grow during the summer and are dormant from fall until mid spring. When dormant, the above ground portion of these plants will dry and the potential fire hazard should be monitored.

VDOT Roadside Turf Mowing Schedule –Ditch lines or steep slope areas

This chart lists the options for low maintenance

		Mowing Height Range	**Mowing Dates [Approx.]**		
Ditchlines	Generally cool season grasses	4" to 6"	Mid May	To Mid June	If cool season grasses dominate, then only a single mowing may be needed. [see the mowing schedule for cool season grass for the timing of this cutting]
Areas adjacent to ditchlines	Generally cool season grasses	4" to 6"			These areas may not need to be mowed unless there is a weed or water flow concern. See the notes for ditchline mowing.
Steep slopes	Grasses and legume mixes	6" to 8"			These areas should be planted with "no mow" species and weed control may be best handled by chemical means, if height control is required.

The subsequent mowings may be needed to control herbaceous and woody growth or if water flow issues require.

Selective chemical control for unwanted vegetation may be an option.

VDOT Roadside Height

	Approximate maximum height in inches that each species may reach
Tall Fescue	36-48
Kentucky bluegrass	24-36
Fine Fescues [Hard Creeping, Chewings, Sheep]	8-18
Bermudagrass	12-15
Zoysiagrass	8-12
Weeping lovegrass	10-16
Orchardgrass	8-12
Switchgrass	84-120
Indiangrass	39-120
Blue grama	8-20
Buffalograss	6-12

The maximum height will vary by cultivar within each species.

Mowing at the prescribed times listed in these charts should allow most PTO driven rotary mowers to produce a clean and attractive cut.

If the grasses are allowed to reach full height and maturity their physical makeup changes to become stiffer and drier with less soft tissue. This makes it harder for rotary mowers to produce an even cut. The result is usually an unattractive cut with differences in stubble height and clumps of cut grass on the surface. There is an extra energy cost to mow this tougher grass as well as increased wear on the machines. Flail type mowers spin faster than PTO rotary mowers and therefore create more energy to cut the grass. The design of the flail mower allows it to cut the clippings several times before they exit the mower. These elements allow the flail mower to produce a cleaner cut when mowing tall mature grass. The drawbacks of the flail mower are the relatively small width of cut and the extra expense of the machine.

The primary key to a good looking cut is the sharpness of the mower blades.