2012

Effects of seeding rates of perennial ryegrass (Lolium perenne L.) on sediment loading and nutrient transport via surface runoff

Jason Robert Anderson
Louisiana State University and Agricultural and Mechanical College, janderson@lsu.edu

EFFECTS OF SEEDING RATES OF PERENNIAL RYEGRASS (*Lolium perenne* L.) ON SEDIMENT LOADING AND NUTRIENT TRANSPORT VIA SURFACE RUNOFF

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

Department of Agronomy

by
Jason R. Anderson
B.S., North Dakota State University, 2008
December 2012

Acknowledgments

I would like to begin by thanking my family for encouraging me to pursue a master's degree. I especially want to thank my mom and dad for their support not only throughout this thesis process but for all the lessons that you have taught me in my life. I will always love and cherish you.

This thesis would have not been possible without the contributions of Dr. Ron Strahan and Dr. Charles Johnson. Thank you for the encouragement and knowledge that you provided me. I want to give a special thanks to the staff at LSU Burden Research Center for the use of their facility to conduct these experiments and for the friendship and camaraderie that I will not forget.

Above all, I would like to thank Dr. Jeffrey Beasley. I honestly could not have done this without your guidance, not only through the thesis process, but also in life. You have taught me much more than I would have ever imagined. I am proud to say you are my advisor, but also a friend and now a colleague.

Table of Contents

List of Tables

List of Figures

Abstract

Sediment loading and nutrient losses from construction sites through surface runoff can have detrimental effects on nearby water bodies. In the late Autumn through early Spring a perennial warm-season grass cannot be established once construction activities have been completed. Often cool-season grasses such as perennial ryegrass (*Lolium perenne* L.) are established for temporary coverage until environmental conditions are suitable for warm-season grass establishment. The purpose of this research was to 1) determine if higher seeding rates of perennial ryegrass accelerate establishment thus reducing sediment loading and 2) determine if watering-in fertilizer applications would reduce nutrient losses through surface runoff. In the first experiment trays were seeded at 0, 195, 390, or 585 kg ha^{-1} with 30-min rainfall simulations performed at 16.3 L per minute at 14, 28 and 42 days after seeding (DAS). Increasing seeding rates reduced total sediment loading 48% to 67% and 86% of sediment eroded from bare soil over the 42-day establishment period. Sediment losses were highest during the initial rainfall simulation at 88, 93, 83, and 62% of total sediment lost from 195, 390, or 585 kg ha^{-1} and bare soil controls, respectively. In the second experiment, the effect of irrigation as a best management practice post fertilizer application was evaluated, Established perennial ryegrass was fertilized at 50 kg N ha^{-1} with grass swards not irrigated or irrigated at 1.25 cm 48 hours prior to rainfall simulation. Thirty-minute rainfall simulations were performed 2 and 7 days after fertilization (DAF). Non-irrigated fertilizer treatments resulted in the highest TKN losses of 12.3 kg N ha^{-1}, moderate dissolved N losses at 3.1 mg N ha^{-1}, and highest TP losses of 2.4 P ha^{-1} 2 DAF compared to 7.0 kg TKN ha^{-1}, 5.2 kg DN ha^{-1}, and 2.0 kg TP ha^{-1} for irrigated fertilizer treatments. At 7 DAF, iIrrigated fertilizer treatments resulted in higher dissolved N losses of 3.1 kg N ha^{-1} compared to 0.1 kg N ha^{-1} for non-irrigated treatments but similar TKN and TP losses of 0.8 kg N ha^{-1} and 0.4 kg P ha^{-1} compared to 0.9 kg N ha^{-1} and 0.2 kg P ha^{-1} lost from non-irrigated treatments. The two experiments showed increasing perennial ryegrass seeding rates during establishment can significantly reduce sediment losses; while irrigating post N fertilization of established swards may not reduce N losses during surface runoff.

Chapter 1: Literature Review

Perennial Ryegrass Origin, Identification, Characteristics, and Establishment

Perennial ryegrass (PR) (*Lolium perenne* L.) is a cool-season perennial grass species adapted to climates with mild winters and cool, moist summers similar to its origins in southern Europe, western Asia, and northern Africa (Beard, 1973; McCarty, 2001). However, PR grown in warmer climates is primarily used as an overseed to dormant warm-season grasses or as temporary cover until a more suitable perennial grass species can be established.

Perennial ryegrass is a bunch type grass that can be identified as having medium leaf texture with dark green color, folded vernation, membranous ligule, small claw-like auricles, and divided blade with ridges on the adaxial surface and glossy on the abaxial surface. The inflorescence is a spike with awnless spiklets (Turgeon, 2011). Seeds are typically viable and harvested for sale for use in PR establishment.

In general, perennial ryegrass exhibits poor tolerance to environmental extremes such as cold, heat, and drought compared to other cool-season grasses (McCarty, 2001). Perennial ryegrass grows best in soil temperatures between 16-24 degrees C in soils that are neutral to slightly acidic, moist and have moderate to high fertility (Emmons, 1995). Perennial ryegrass is typically maintained at 1.25 to 5 cm in high maintenance sites or left un-mowed in utility areas. Fertility ranges for increased grass vigor are typically between 1 to 3 kg N $100m^{-2}$ yr^{-1}(Turgeon, 2011; Emmons, 1995; Fry and Huang, 2004; Beard, 1973).

There are numerous perennial ryegrass cultivars with finer, denser leaf textures that have been bred to withstand greater environmental stresses including heat or wear tolerances compared to the more common PR species. These cultivars are generally used for more highly managed grass areas such as golf courses or athletic fields. Utilitarian areas are still predominantly sown using common PR species.

Perennial ryegrass, produced through seed germination, has thick vascular bundles providing established areas with good wear resistance, good soil compaction tolerance, and fast establishment rates (McCarty, 2001). Although easy to establish, PR is susceptible to common diseases including red-thread (*Laetisaria fuciformis*), dollar spot (*Rutstroemia floccossa*), brown patch (*Rhizoctonia solani*), gray leaf spot (*Pyricularia grisea*), and *Pythium* blight (Emmons, 1995). Because perennial ryegrass can germinate quickly and establish in a short duration, it is commonly used in conjunction with other cool-season grasses to avoid erosion in sloped areas during establishment throughout various climates (Emmons, 1995). Perennial ryegrass can be incorporated into the seedbed in a variety of ways including drop spreaders and fertilizer spreaders for smaller areas, cultipacker seeders and hydromulch for larger areas (Turgeon, 2011).

Nitrogen and Phosphorus Cycles

Plants require nitrogen in the highest concentrations in order to complete their life cycles. However, atmospheric nitrogen (N_2) is the most prevalent form of nitrogen at over 99% of nitrogen distribution throughout plant-soil-atmosphere continuum (Havlin et al., 1999). Within the soil, this macro-nutrient is predominantly unavailable for plant uptake because it is a constituent of insoluble organic compounds. However, through a process known as mineralization, micro-organisms breakdown soil organic matter to release nitrogen in the inorganic form of ammonium (NH_4). Ammonium released by mineralization can be readily absorbed by plant roots for plant growth. Rates of nitrogen mineralization in soils have been estimated at 1.5 to 3% of total organic nitrogen per year depending on temperature and moisture and can constitute a large portion of the annual nitrogen uptake of many plants (Brady and Weil, 1999).

Ammonium absorbed by plants can be assimilated and transferred throughout the plant for proper growth and development. However, ammonium that remains within the soil is subject to the reverse process of mineralization known as immobilization or other processes such as ammonia (NH_3) volatilization, fixation by clay minerals or nitrification. Volatilization of ammonium is the conversion of ammonium to ammonia in alkaline soils and drier environments. In the process of nitrification, *Nitrosomonas sp.* and *Nitrobacer sp.* break down NH_4 and enzymatically oxidize NH_4 in a two step process mediated by temperature, moisture, aeration, initial ammonia concentrations, readily available carbon sources and soil pH (Havlin et al., 1999). Nitrification of NH_4 produces NO_2 in the first step with conversion to NO_3 in the second phase of nitrification. Once formed, nitrate can be absorb by the plant and transferred throughout the tissues for proper growth and development.

Once nitrogen is in the nitrate form, nitrogen can be lost from leaching, plant uptake through mass flow, or denitrification by microorganisms. Nitrate losses from denitrification involve conversion of nitrate into the gaseous forms of 2NO, N_2O, or N_2 with movement directly into the atmosphere. Denitrification typically occurs when nitrate is available, readily decomposable carbon sources are present, the soil air contains less than 10% oxygen (e.g. flooded soils), and temperatures are between 2 to 50 C (Brady and Weil, 1996). Denitrification represents a method of nitrogen loss from the soil system. Other methods for nitrate losses include leaching and transport by surface runoff. Leaching is a process by which water-soluble, negatively charged nitrate molecule is moved in draining water downward in the soil below the zone of root uptake. Leaching of nitrogen is more prone in sandy soils with high infiltration and percolation rates and low anion exchange capacity and organic matter. Surface runoff represents the movement of nitrate and other soluble nitrogen forms or eroded sediment bound nitrogen through lateral water flow. Both leaching and surface runoff have been cited for numerous environmental issues most often related to eutrophication (Easton and Petrovic, 2004; Gross et. al, 1990; Bowman et al., 1998; Linde and Watschke, 1997; Petrovic, 1990; Burwell et al., 2011).

Similar to nitrogen, phosphorus is a macro-nutrient. Phosphorus primary function is energy storage and transfer within plants. Although phosphorus is a macro-nutrient, it can be scarce in soil solutions. In heavily fertilized soils, phosphorus concentrations can reach 1 mg L^{-1} compared to 0.001 mg L^{-1} in infertile soils (Brady and Weil, 1996). Phosphorus' primary function is energy storage and transfer within plants in processes including photosynthesis, nitrogen fixation, flowering, seed production and maturity. Low phosphorus concentrations, rarely exceeding 0.01% of total phosphorus in some soils, plant availability becomes an important factor for growth and development especially in the production of lateral and fibrous root systems (Brady and Weil, 1996; Turgeon, 2011; Fry and Huang, 2004). In healthy leaf tissue, total phosphorus comprises 0.2 to 0.4% of dry matter (Brady and Weil, 1996).

Within plants, phosphorus is a component of Adenosine triphosphate, ATP, a high energy phosphate group synthesized through photosynthesis and respiration (Fry and Huang, 2004; Brady and Weil, 1996). Also of great importance, phosphorus is involved in Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), codes for protein synthesis for all living organisms (Brady and Weil, 1996). Finally, phosphorus is used in the formation of phospholipids a component of cellular membranes to help regulate solute movement into and out of cells.

In the soil, phosphorus must be dissolved in the soil solution to be available for plant uptake. Phosphorus is generally absorbed as phosphate ions HPO_4^- and $H_2PO_4^-$ through diffusion into plant roots. Although HPO_4^- , a monovalent anion, dominates acidic soil solutions, $H_2PO_4^-$ is the predominate form in alkaline soils (Brady and Weil, 1996; Havlin et al., 1999). This is due to organic phosphorus being bound by calcium in alkaline soils while inorganic phosphorus is typically bound by iron or aluminum in acidic soils. Phosphorus held in organic form can be mineralized or immobilized by microbes under environmental factors similar to the nitrogen releasing process. Once soluble, phosphorus is released by organic residues or humus, the resulting inorganic $H_2PO_4^-$ is subject to plant uptake or chemical reactions with iron, aluminum, manganese, or calcium that render it insoluble and unavailable to plants (Havlin et al., 1999).

Management of phosphorus fertility is not only important for proper plant growth and development, but is a key to reducing phosphorus movement and associated environmental issues. Research has shown offsite movement of phosphorus in watersheds and open water bodies can have devastating effects on aquatic organisms as a result of eutrophication (Mallin and Wheeler, 2000; Shuman, 2004; Austin et al., 1996; Gross et al., 1990; Hay et al., 2007; Sharpley et al., 1994; Flemmng and Cox, 2001).

Nitrogen and Phosphorus Losses via Surface Runoff

Eutrophication, from excess N and P transport by surface runoff results in algal blooms, decreased oxygen concentrations, and unsuitable environments for many aquatic organisms. Phosphorus at levels as low as 0.01 and 0.035 mg L^{-1} have been reported to cause eutrophication (Mallin and Wheeler, 2000) and Valiela et al. (1997) reported NO_3-N to be a limiting factor for eutrophication and algal blooms. Vegetation has been recognized as being capable of reducing pollutant transfer by surface runoff (Gross et al., 1990; Morton et al., 1988). Krenitsky et al. (1998) showed grass canopies reduce sediment erosion and detachment by decreasing raindrop kinetic energy as well as reducing subsequent transport of ions attached to soil colloids.

In general, proper fertilization practices may not necessarily cause excessive nutrient losses from turfgrass (Easton and Petrovic, 2004). Gross et al. (1990) found runoff losses of NO_3-N from established turf to be low (<1% of applied fertilizer). Miltner et al. (1996) recovered very low levels of ^{15}N-labeled urea leachate, representing only 0.23% of the applied N from Kentucky bluegrass (*Poa pratensis* L.). In 2002, Bowman et al. examined the fate and transport of nitrogen with multiple warm-season turfgrasses. They reported leaching losses were unusually high following the first N application ranging from 48 to 100% and 4 to 16%, respectively for NO_3 and NH_4. Hay et al. (2007) reported similar findings to Bowman et al. (2002) with high NO_3 losses from sod and sprigged Tifway bermudagrass during the initial 50 d after initial application.

In a 1997 study, Cole et al. experimented with nutrient losses in bermudagrass by running rainfall simulations when the soil was dry and after natural rainfall moistened the soil. Cole et al. reported nutrient losses of 2% and 10-15% for dry and wet soil respectively. Similarly, Shuman (2004) found phosphorus data values for without watering-in are about 14 to 16% whereas watering-in values are only 3 to 5%, or about a five times decrease for watering-in and waiting three days before the first event. Additionally, Austin et al. (1996) reported phosphorus runoff from a pasture was mostly soluble phosphorus and not adsorbed to soil particles. Austin et al. applied P at 22 kg and 88 kg P ha^{-1} and found total phosphorus lost was 35% and 17% respectively. However, Fleming and Cox (2001) found 98% of total phosphorus was lost in overland flow. Thus rainfall volume and intensity along with soil moisture can be important factors in water and nutrient runoff (Shuman, 2004).

Hay et al. (2007) claims a major percentage of the phosphorus in runoff in agricultural systems are adsorbed to particles that are then carried by water. However, Sharpley et al. (1994)

reports little soil particle movement in established turfgrass and pastures and most phosphorus is transported by surface runoff in the soluble form (Gross et al., 1990). Hay et al. (2007) measured phosphorus concentrations before and after rainfall simulations during Tifway bermudagrass establishment. Hay et al. (2007) measured phosphorus concentrations before rainfall events at 0.009, 0.009, and 0.011 g m^{-2} for manure grown sod, fertilizer grown sod, and sprigs, respectively. However, leaching losses of dissolvable P for manure grown sod, fertilizer grown sod, and sprigs measured 0.008, 0.007, and 0.009 g m^{-2} respectively, concluding dissolvable P had no significant leaching post rainfall simulations. In addition to Hay et al. (2007), Vietor et al. (2004) reported Kentucky bluegrass sequesters up to 50% of applied N and 88% of applied P.

Sediment Losses via Surface Runoff

Turfgrass establishment is perhaps one of the most susceptible periods for erosion and surface water contamination. Dense growth habits of established turfgrass can reduce sediment losses by providing an indirect pathway for runoff water. Evapotranspiration is generally the largest source of soil water removal in a turfgrass ecosystem resulting in the largest sink of nutrients in a turfgrass ecosystem (Easton and Petrovic, 2004; Petrovic, 1990). However, increasingly high soil moisture levels caused by prolonged periods of rainfall or irrigation can be responsible for large runoff and nutrient losses (Linde et al., 1995). Ebdon et al. (1999) reports that dense stands of turfgrass such as Kentucky bluegrass is highly efficient at removing water from the soil lowering the potential of runoff and leaching by the reduction of soil moisture. Established turfgrass systems are able to retain large quantities of precipitation, reduce the impact of raindrops, decrease water runoff rates and volumes, absorb nitrogen and phosphorus into vegetative tissue, enhance soil stability through root biomass, and increase soil infiltration

(Linde et al., 1995, 1998; Gross et al., 1990; Morton et al., 1988; Pearce et al. 1997; Bowman et al., 2002). However, the combination of little ground cover, high application rates of soluble fertilizers and frequent irrigation during vegetation establishment create a situation prone to runoff and leachate losses (Easton and Petrovic, 2004).

In a 1995 study, Linde et al. reported a mature creeping bentgrass (*Agrostis stolonifera* L.) verdure intercepted 113% more water compared to PR. Surface water runoff was similar in days post-seeding, but as each sward matured, runoff from PR occurred earlier accompanied with greater volumes compared to creeping bentgrass. They attributed the difference in species performance to shoot density. Creeping bentgrass' dense canopy and thatch forming growth habit produced a more tortuous pathway for downward and horizontal movement of water, increased hydraulic and surface resistance for greater soil infiltration, and horizontal shoot and leaf orientation for interception of soil particles (Linde et al., 1995).

In a subsequent study by Linde and Watschke in 1997, they examined the effects of sediment transport through creeping bentgrass and PR on 9-11% sloped plots. After verticutting each plot (6.5 m wide and 19 m long), they reported an average of 67 kg and 20 kg of plant biomass and organic material was removed from creeping bentgrass and PR respectively. After rainfall simulations, trace amounts (0.8 kg ha^{-1}) of sediment were transported via runoff. In six samples where sediment was detected, Linde and Watschke reported the highest concentration of sediment at 26 mg L^{-1} for creeping bentgrass producing 170 L of runoff in 100 minutes resulting in soil losses of 0.36 kg ha^{-1}.

In a related study, Wauchope et al. (1991) used a mixed stand of bermudagrass and bahiagrass (*Paspalum notatum* Flugge) for sediment loss and runoff experiments. Wauchope et al. conducted simulated rainfalls to bare and grassed plots at a rate of 69 mm h^{-1}. Average soil losses reported were 28 kg ha^{-1} and 8 kg ha^{-1} for bare and grassed areas, respectively. Similarly, Gross et al. (1991) reported soil losses from bare soil and sloped tall fescue (*Festuca arundinacea* Schreb.) during rainfall simulated at 30-min, 120 mm h^{-1}. They reported runoff and sediment losses were significantly reduced from tall fescue (54 kg ha^{-1}) compared to losses from bare soil (519 kg ha^{-1}) during rainfall simulations.

Literature Cited

Austin, N.R., J.B. Prendergast, and M.D. Collins. 1996. Phosphorus losses in irrigation runoff from fertilized pasture. J. Environ. Qual. 25:63-68.

Beard, J.B. 1973. Turfgrass: Science and Culture. Prentice-Hall, Inc. Englewood Cliffs, NJ. 101-102; 445-446.

Bowman, D.C., D.A. Devitt, M.C. Engelke, T.W. Rufty. 1998. Root architecture affects nitrate leaching from bentgrass turf. Crop Science 38:1633-1639.

Bowman, D.C., C.T. Cherney, and T.W. Rufty. 2002. Fate and transport of nitrogen applied to six warm-season turfgrasses. Crop. Sci. 42:833-841.

Brady, N.C., R.R. Weil 1996. The Nature and Properties of Soils: Eleventh Edition. Prentice-Hall, Inc. Upper Saddle River, NJ. 401-431; 445-472.

Burwell, R.W.; J.S. Beasley, L.A. Gaston, S.M. Borst, R.E. Sheffield, R.E. Strahan, and G.C. Munshaw. 2011. Losses of surface runoff, total solids, and nitrogen during bermudagrass establishment on levee embankments. J. Environ. Qual. 40: 1241-1248.

Cole, J.T., J.H. Baird, N.T. Basta, R.L. Huhnke, D.E. Storm, G.V. Johnson, M.E. Payton, M.D. Smolen, D.L. Martin, and J.C. Cole. 1997. Influence of buffers on pesticide and nutrient runoff from bermudagrass turf. J. Environ. Qual. 26:1589-1598.

Easton, Z.M. and A.M. Petrovic. 2004. Fertilizer source effect on ground and surface water quality in drainage from turfgrass. J. Envrion. Qual. 33:645-655.

Ebdon, J.S., A.M. Petrovic, and R.A. White. 1999. Interaction of nitrogen, phosphorus, and potassium on evapotranspiration rate and growth of Kentucky bluegrass. Crop Sci. 39:209-218.

Emmons, Robert D. 1995. Turfgrass Science and Management: Second edition. Delmar Publishers. Albany, NY. 69-72.

Gross, C.M., J.S. Angle, and M.S. Welterlen. 1990. Nutrient and sediment losses from turfgrass. J. Environ. Qual. 19:663-668.

Gross, C.M., J.S. Angle, R.L. Hill, and M.S. Welterlen. 1991. Runoff and sediment losses from tall fescue under simulated rainfall. J. Environ. Qual. 20:604-607.

Fleming, N.K. and Cox, JW. 2001. Carbon and phosphorus losses from dairy pasture in South Australia. Australian Journal of Soil Research 39: 969-978.

Fry, Jack and B. Huang. 2004. Applied Turfgrass Science and Physiology. John Wiley & Sons, Inc. 41-54.

Havlin, John L.; J.D. Beaton; S.L. Tisdale; W.L. Nelson. 1999 Soil Fertility and Fertilizers: An Introduction to Nutrient Management. Sixth Edition, Prentice Hall, Inc. 86-195.

Hay, F.J., D.M. Vietor, C.L. Munster, R.H. White, and T.L Provin. 2007. Leaching loss of NO3-N and dissolved P from manure and fertilizer during turfgrass establishment. Plant Soil 296:1-17.

Humphry, J.B., T.C. Daniel, D.R. Edwards, and A.N. Sharpley. 2002. A portable rainfall simulator for plot-scale runoff studies. Applied Engineering in Agriculture. 18:199-204.

Krenitsky, E.C., M.J. Carroll, R.L. Hill, and J.M. Krouse. 1998. Runoff and sediment losses from natural and man-made erosion control materials. Crop Sci. 38: 176-182.

Linde, D.T., T.L. Watschke, and A.R. Jarrett. 1998. Surface runoff comparison between creeping bentgrass and perennial ryegrass turf. J. Turfgrass Manage. 2:11-33.

Linde, D.T., T.L. Watschke, A.R. Jarrett, and J.A. Borger. 1995. Surface runoff assessment from creeping bentgrass and perennial ryegrass turf. Agron. J. 87:176-182.

Linde, D.T., and T.L. Watschke. 1997. Nutrients and sediment in runoff form creeping bentgrass and perennial ryegrass turfs. J. Environ. Qual. 26:1248-1254.

Mallin, M.A. and T.L. Wheeler. 2000. Nutrient and fecal coliform discharge from coastal North Carolina golf courses. J. Environ. Qual. 29:979-986.

McCarty, L.B. 2001. Best Golf Course Management Practices. Prentice-Hall, Inc. Upper Saddle River, NJ. 362

Miltner, E.D., B.E. Branham, E.A. Paul, and P.E. Rieke. 1996. Leaching and mass balance of 15N-labeled urea applied to a Kentucky bluegrass turf. Crop Sci. 36:1427-1433.

Morton, T.G., A.J. Gold, and W.M. Sullivan. 1988. Influence of over-watering and fertilization on nitrogen losses from home lawns. J. Enviorn. Qual. 17: 124-130.

Pearce, R.A., M.J. Trlica, W.C. Leininger, J.L. Smith, G.W. Frasier. 1997. Efficiency of grass buffer strips and vegetation height on sediment filtration in laboratory rainfall simulations. J. Environ. Qual. 26: 139-144.

Petrovic, P.M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Environ. Qual. 19:1-14

Sharpley, A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel, and K.R. Reddy. 1994. Managing agricultural phosphorus for protection of surface waters: issues and options. J. Environ. Qual. 23:437-451.

Shuman, L.M. 2004. Runoff of nitrate nitrogen and phosphorus from turfgrass after watering-in. Communications in Soil Science and Plant Analysis 35: 9-24.

Turgeon, A.J. 2011. Turfgrass Mangement: Ninth edition. Pearson Education, Inc. Upper Saddle River, NJ. 82-84; 320-328.

Valiela, I., G. Collins, J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, and C.H. Sham. 1997. Nitrogen loading from coastal watersheds to receiving estuaries. New method and application. Ecol. Appl. 7:358-380.

Vietor, D.M., T.L. Provin, R.H. White, and C.L. Munster. 2004. Runoff losses of phosphorus and nitrogen imported in sod or composted manure for turf establishment. J. Environ. Qual. 33:358-366.

Wauchope, R.D, J.R. Young, R.B. Chalfant, L.R. Marti, H.R. Sumner. 1991. Deposition, mobility and persistence of sprinkler-irrigation-applied chlorpyrifos on corn foliage and in soil. Pesticide Science 32: 235-243.

Chapter 2: Increasing Perennial Ryegrass Seeding Rate Reduces Sediment Loading During Establishment

Sediment loading via surface runoff is an environmental concern especially in areas subject to construction activities (Daniel et al., 1979; Kuo et al., 1988; and Schuler, 1987). The United States Environmental Protection Agency has recognized sediment as one of the most prevalent pollutants of open water bodies throughout the United States (USEPA, 1983). Sediment loading increases water turbidity that in turn negatively affects aquatic organisms and vegetation; increases chemical and nutrient loading; and potentially alters hydraulic characteristics (Burwell et al., 2011; Linde et al., 1995, 1998; Krenitsky et al., 1998).

Current best management practices to limit sediment movement often include planting vegetation in affected or riparian areas to limit runoff incidence and filter runoff before entering receiving waters (Gross et al., 1990, 1991; Krenitsky et al., 1998; Linde and Watschke, 1997). Several studies have demonstrated the ability of vegetation to reduce surface runoff and erosion compared to fallow soils (Daniel et al, 1979; Gross et al., 1990; Linde et al., 1995; Easton and Petrovic, 2004). As a result, grasses are often prescribed as a best management practice because many species are perennial, relatively easy to establish, and effective barriers to sediment movement.

In areas with sub-tropical climates similar to southern Louisiana where construction can occur year round, perennial or annual ryegrasses (*Lolium perenne* L.; *Lolium multiflorum* L.) are typically planted from October to March post-construction because environmental conditions are unsuitable for establishing a perennial warm-season grass species (Turgeon, 2011) and erosion control measures are required within 30 days after construction completion for areas larger than five acres (LDEQ, 2011). Temporary vegetative coverage with ryegrass has been shown to reduce erosion while maintaining embankment structural integrity until environmental conditions are conducive for warm-season perennial grass species establishment (Burwell et al., 2011).

Positive relationships between grass coverage or tiller density have been correlated to increased runoff resistance and reduced sediment loading (Easton and Petrovic, 2004; Burwell et al., 2011). The establishment phase represents a period in which a site is highly susceptible to erosion due to bare or sparse vegetative coverage. In a study examining common bermudagrass (*Cynodon dactylon* L.) coverage effects on earthen levee embankment erosion in south Louisiana, Burwell et al. (2011) reported 62 to 90% of total sediment loading during establishment (>85% coverage) occurred when there was <50% grass coverage. They also reported the application of water-soluble nitrogen to accelerate common bermudagrass establishment did not sufficiently accelerate ground coverage to reduce overall sediment loading during establishment; but resulted in increased nitrogen losses in runoff waters.

For areas that need temporary vegetative coverage, increasing seeding rates during establishment of large utility areas may be a simpler and safer alternative to increased fertility practices to achieve higher ground coverage for greater runoff resistance. Because vegetation specifications for construction sites vary from state-to-state and between contracting entities, it is not uncommon to find perennial ryegrass (PR) application rates <196 kg ha^{-1}. Therefore, the objective of this study was to examine the effect PR seeding rate has to accelerate ground coverage to reduce sediment loading from surface runoff during establishment.

Material and Methods

Perennial Ryegrass Establishment in Runoff Trays

The study was conducted at the Louisiana State University Agricultural Center Burden Research Facility in Baton Rouge, La in October 2011 and January 2012. Sixteen trays (13.5 cm x 200 cm x 75 cm) within internal areas of 1.5 m^2 were filled and compacted with a soil consisting of 57.3% clay, 32.1% silt, and 9.8% sand collected from the Bonnet Carre Spillway borrow pit located near LaPlace, La. Soils had pH 8.1 with fertility concentrations of 62.4 mg P kg^{-1} and 338.7 mg K kg^{-1}. Soil-filled trays were placed in a greenhouse on wooden pallets to facilitate tray movement under the rainfall simulator. Trays were used rather than a field study so that runoff from natural rainfall events would not confound runoff comparisons.

Trays were seeded with perennial ryegrass at 195, 390, or 585 kg PLS ha^{-1} and unseeded bare soil controls with 4 replications. Immediately after seeding, irrigation was applied to ensure adequate soil moisture for seed germination. Following seed emergence, irrigation was applied with 1.25 cm every 3 days for the first 14 days and every 5 days the remainder of the study. No fertilizer or pesticides were applied throughout the 42-day study.

Rainfall Simulation Setup

Thirty-minute rainfall simulations were conducted at 14, 28, and 42 days after seeding. The method followed for rainfall simulation was outlined by the United States Department of Agriculture's (USDA) National Phosphorous Research Project's (NPRP) protocol for rain simulation (USDA, 2008). Trays were fixed at a 20° slope and simulated rainfall applied using the Tlaloc 3000 Rainfall Simulator (Joern's Inc.; West Lafayette, IN), a field mobile unit based on the designs of Miller (1987) and Humphry et al. (2002). The Tlaloc 3000 contains a Spraying Systems Co. Fulljet ½HH SS 50WSQ nozzle with a spray angle of 104° (±5%) that delivered 16.3 L per minute at 7 psi (USDA, 2008). The rainfall intensity selected for simulations represents a 10-year historical high for Baton Rouge, La (Louisiana Office of State Climatology, 2010). All water used for rainfall simulations was from a municipal source. Because rainfall simulations occurred within a greenhouse, the nozzle and associated plumbing assemblies were removed from the Tlaloc 3000 enclosure and mounted 3 m above the soil surface of the trays. Tarps were hung around the single-tray rainfall simulation area to limit wind disturbance. During simulations, surface runoff flowed to the lower side of the trays through PVC gutters into 117 L collection reservoirs and weighted

Prior to rainfall simulation canopy coverage was photographed for digital analysis (Systat Software, Inc.; San Jose, CA); tiller density was assessed in a 25 cm^2; and soil moisture measured using EC-5 (Decagon Devices, Pullman, WA) probes within 30 minutes of rainfall simulation. During rainfall simulations, measurements included the time until the onset of runoff and total runoff volume. At the end of the 30-min rainfall simulation, composite water samples were collected and analyzed for sediment concentrations following EPA method 160.2 (USEPA, 1999) with the modification of using 40 mL samples. During the second study, water samples were collected every 5 min for 30 min to assess sediment losses over the 30-min runoff period.

Statistical Analysis

Vegetative data concerning coverage and tillering as well as runoff data concerning sediment loading were analyzed using the GLM procedure in the statistical software SAS (SAS, 2008). PR seeding rate was the only fixed effect imposed on soil-filled trays arranged in a complete randomized design maintained under a greenhouse environment. Means were separate by date using Fisher's protected least significant difference at a significance of $p \leq 0.05$. Runoff data concerning time until the onset of runoff and runoff volumes were regressed against PR coverage with the linear equation listed. Data were combined for all analyses across experiments when the interaction term of experiment and seed treatment was not significant at a level of $p \leq 0.20$.

Results

Perennial Ryegrass Establishment

Perennial ryegrass ground coverage was accelerated over the 42-day establishment period by increasing seeding rate from 195 to 585 kg ha^{-1}. At 14 DAS, the lowest seeding rate resulted in 22% ground coverage compared to 48 and 63% ground coverage for the moderate and higher seeding rates, respectively, and corresponding tiller densities of 23, 35, and 47 cm^2 (figure1, figure 2).

The trend of higher ground coverage with increasing seeding rate continued at 28 DAS with 43, 64, and 79% ground coverage for all seeding rates but swards exhibited a decline in tiller densities for the moderate and highest seeding rates while the lowest seeding rate of 195 kg ha^{-1} was static. However, at 42 DAS no differences in ground coverage occurred between seeding rates with all swards resulting in >80% groundcover. Only the highest seeding rate exhibited significant increased tiller density 42 DAS at 60.5 cm^2compared to 26 and 26.5 cm^2 for the 195 and 390 kg ha^{-1} seeding rates.

Effects of Seeding Rate on Runoff Initiation and Volume

The influence of seeding rate to delay the onset of surface runoff did not differ for the first rainfall simulation. At 14 DAS, seeding rates actually had runoff occur faster compared to bare soil controls. Surface runoff was initiated within 60.5, 49.5, and 55 s for the low, moderate, and high seeding rates, respectively, compared to 177 for the bare soil control (figure 3). The delay in the bare soil is most likely a function of soil moisture prior to rainfall simulation with 23.6, 24.1, 27.4, and 19.6 for the low, moderate, and high seeding rates and bare soil control

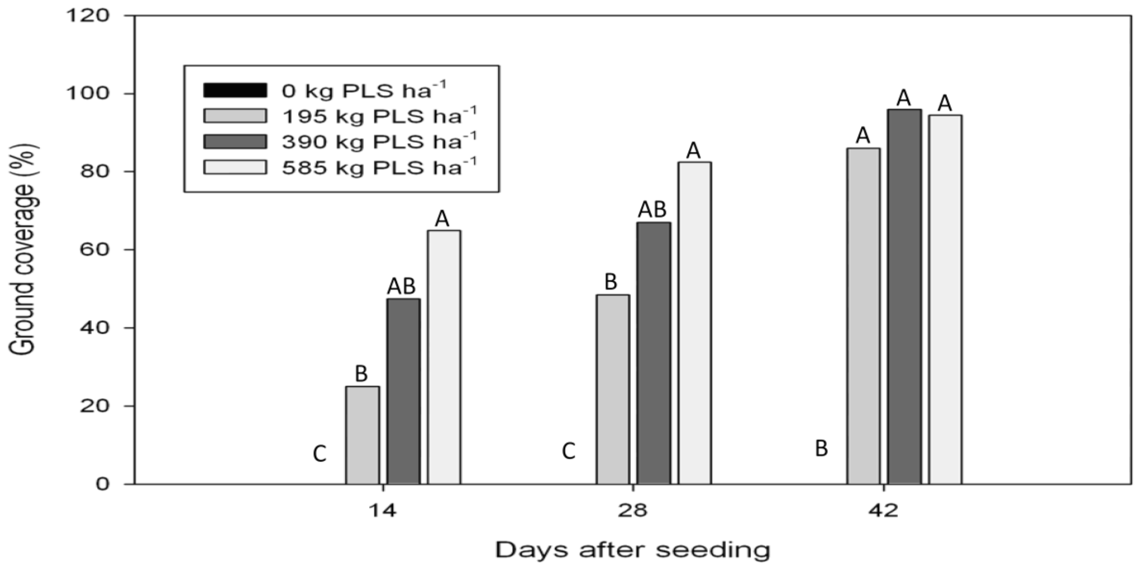

Figure 1. Influence of perennial ryegrass seeding rates (0, 195, 390, and 585 kg ha^{-1}) on ground coverage for rainfall simulations performed at 14, 28, and 42 days after seeding. Ground coverages means are separated by rainfall simulation date using Fisher Protected LSD $_{(\alpha=0.05)}$.

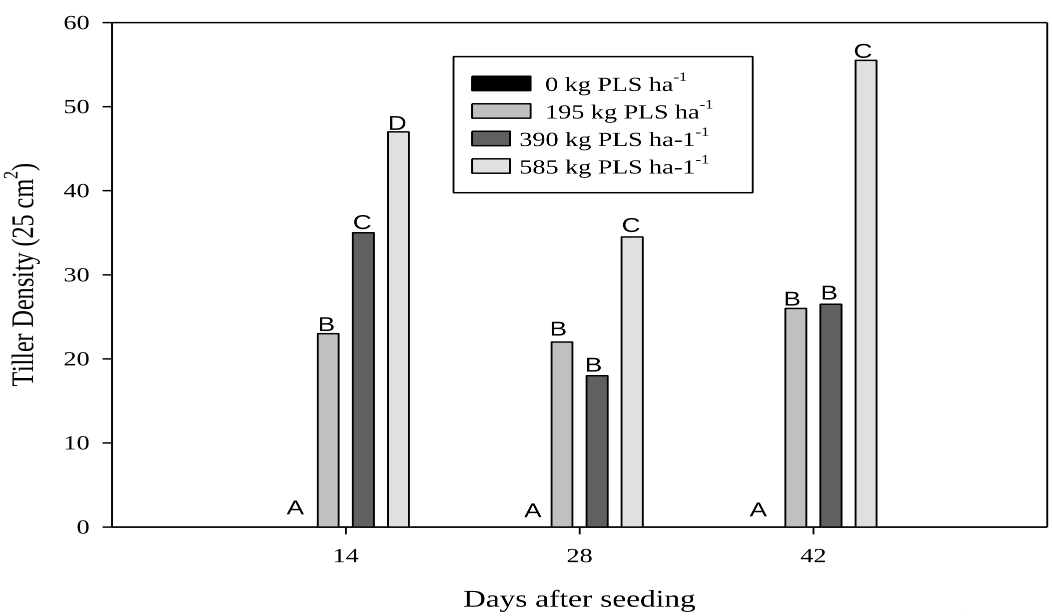

Figure 2. Effect of perennial ryegrass seeding rates (0, 195, 390, and 585 kg ha^{-1}) on sward tiller density 14, 28, and 42 days after seeding. Tiller densities means are separated by rainfall simulation date using Fisher Protected LSD $_{(\alpha=0.05)}$.

14 DAS. At 28 and 42 DAS, PR seeding rate did not affect the duration necessary to delay the onset of runoff at 263, 215, and 302 s 28 DAS for 195, 390, and 585 kg ha^{-1} seeding rates, respectively. All seeded treatments delayed the onset of runoff for a longer duration than bare soil controls. However, 42 DAS there were no differences in the effect of seeding rate to delay runoff at 225 to 285 s, but again all seeding rates increased the duration for runoff compared to 220 s for bare soil controls. Data for the time until the onset of runoff combined across events and regressed against PR ground coverage exhibited a positive relationship illustrating the effect of increasing vegetative coverage to delay runoff (figure 4).

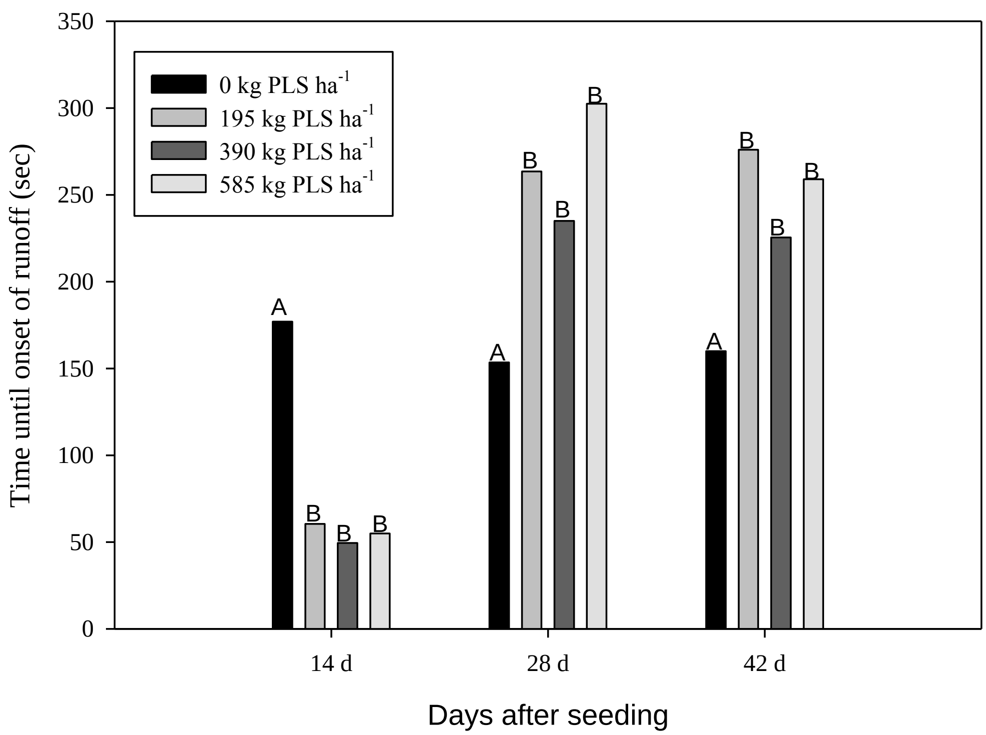

Figure 3. Perennial ryegrass seeding rates (0, 195, 390, and 585 kg ha^{-1}) delay the onset of surface runoff during rainfall simulations performed at 14, 28, and 42 days after seeding. Time duration means are separated by rainfall simulation date using Fisher Protected LSD $_{(\alpha=0.05}$

As was the case for Perennial ryegrass coverage affecting onset of runoff, PR coverage also affected runoff volume. Overall, runoff volume regressed against PR coverage resulted in a negative relationship illustrating declines in runoff volumes as PR coverage increased (figure 5, figure 6). When runoff volume losses are evaluated at each rainfall date, no differences in runoff occurred at 14 DAS between bare soil controls and PR seeding rate treatments. However, at 28 and 42 DAS, all seeding rates reduced runoff volumes compared to bare soil controls with the exception of the 390 kg ha^{-1} PR seeding rate 28 DAS in which the runoff volume of 35 L was comparable to 34.35 L lost from the bare soil control.

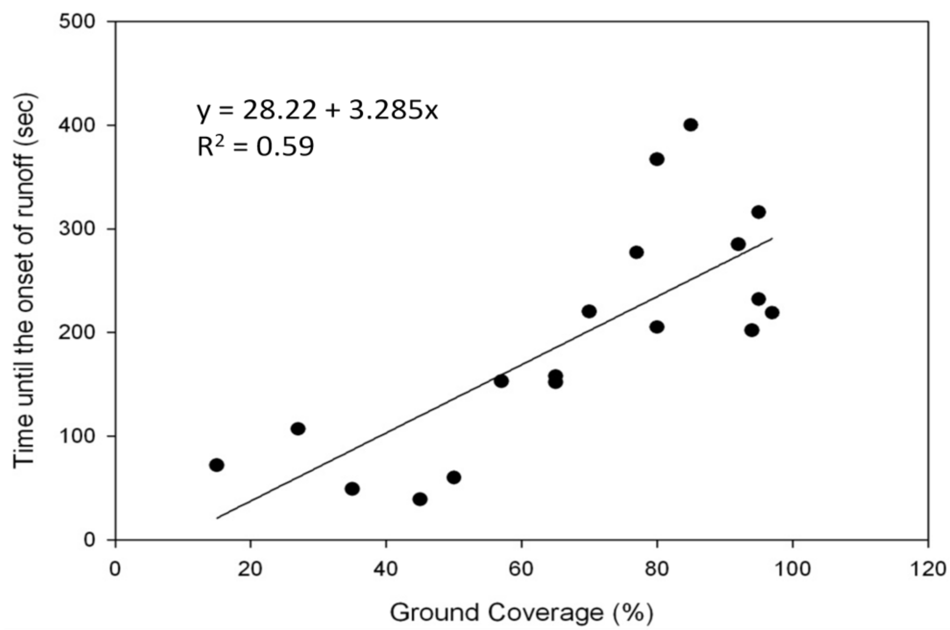

Figure 4. Affects of perennial ryegrass ground coverage to delayed surface runoff from simulated rainfall performed at 14, 28, and 42 days after seeding.

Sediment Loading

Sediment losses were highest for the bare soil control and 195 kg ha^{-1} PR seeding rate at 3406 and 1218 kg ha^{-1} with a step reduction in sediment losses for 390 and 585 kg ha^{-1} PR seeding rates at 427 and 320 kg ha^{-1}, respectively (figure 7). Interesting in the second experiment when sediment losses were accounted every five minutes during the 30-min runoff

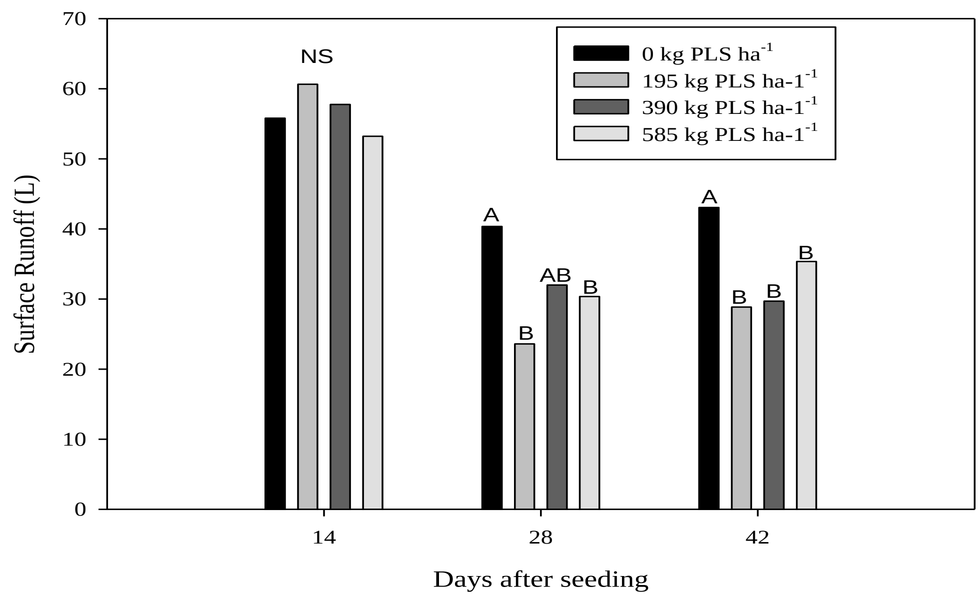

Figure 5. Perennial ryegrass seeding rate (0, 195, 390, and 585 kg ha^{-1}) effects on runoff volume losses from rainfall simulations performed at 14, 28, and 42 DAS. Time duration means are separated by rainfall simulation date using Fisher Protected LSD $_{(\alpha=0.05)}$.

event, after five minutes of runoff, sediment losses from all seeding rates and control were somewhat static with the control exhibiting the highest sediment loss rate of 243.6 kg ha^{-1} compared to 12.8, 11.7, and 26.6 kg ha^{-1} for 195, 390, and 585 kg ha^{-1} PR seeding rates (figure 8). By 28 DAS, all treatments including the bare soil control resulted in declines in sediment losses. However, all seeded treatments exhibited the lowest sediment losses of 864 to 169 kg ha^{-1} compared to 4854 kg ha^{-1} for bare soil controls. This pattern was again observed at the final rainfall simulation 42 DAS. Data combining sediment losses for total sediment lost as a percentage of bare soil controls during the 42-day establishment period exhibited a pattern of decreasing sediment losses with higher PR seeding rates (figure 9). Total sediment loss as a percentage of bare soil controls of 48%, 67%, and 86% corresponded to PR seeding rates of 195, 390, and 585 kg ha^{-1}.

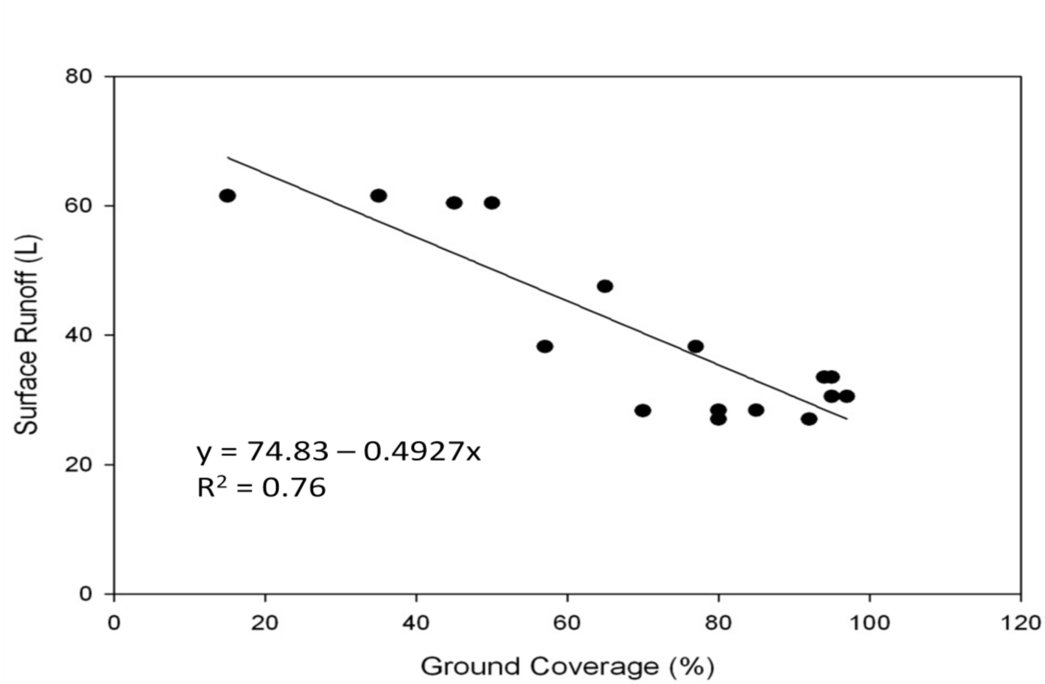

Figure 6. Effect of perennial ryegrass ground cover on surface runoff volume lost during rainfall simulations at 14, 28, and 42 days after seeding.

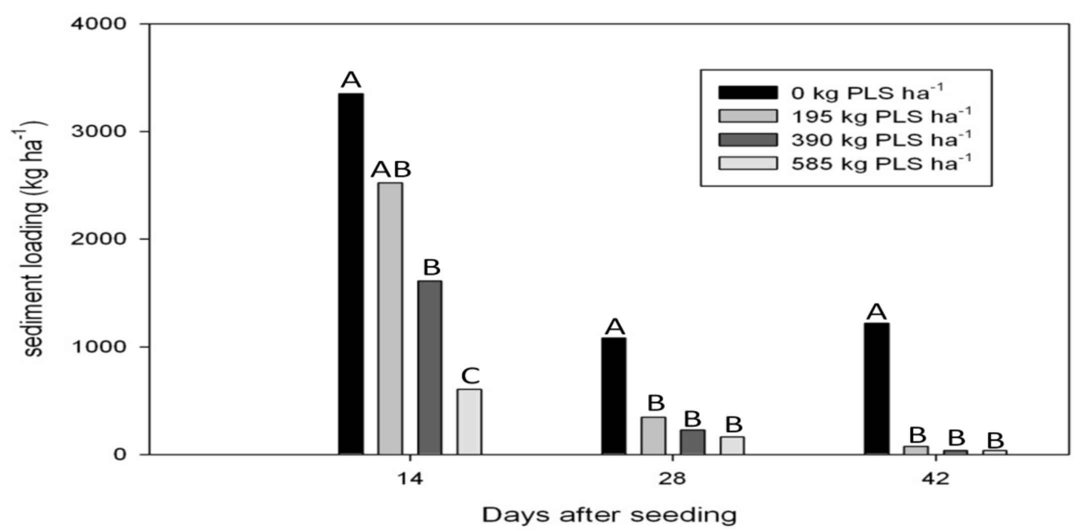

Figure 7. Sediment losses from swards of perennial ryegrass seeded at 0, 195, 390, or 585 kg ha^{-1} and subjected to rainfall simulations 14, 28, and 42 days after seeding. Sediment loading means are separated by rainfall simulation date using Fisher Protected LSD $_{(\alpha=0.05)}$.

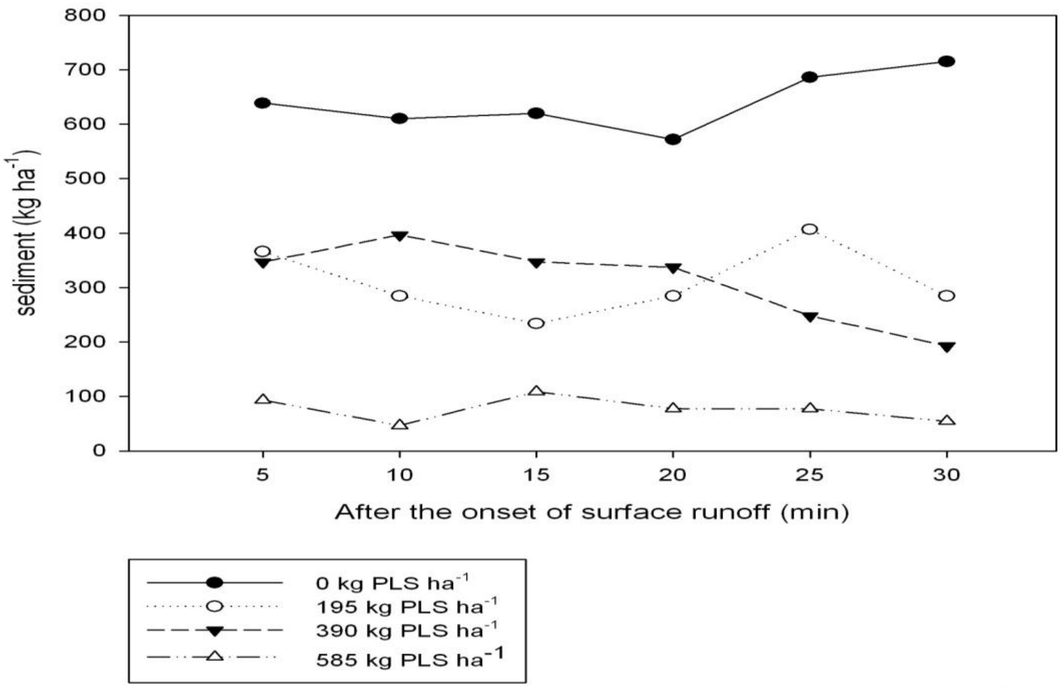

Figure 8. Influence of perennial ryegrass seeding at 0, 195, 390, or 585 kg ha^{-1} on sediment losses during a 30-min rainfall simulation 14 days after seeding.

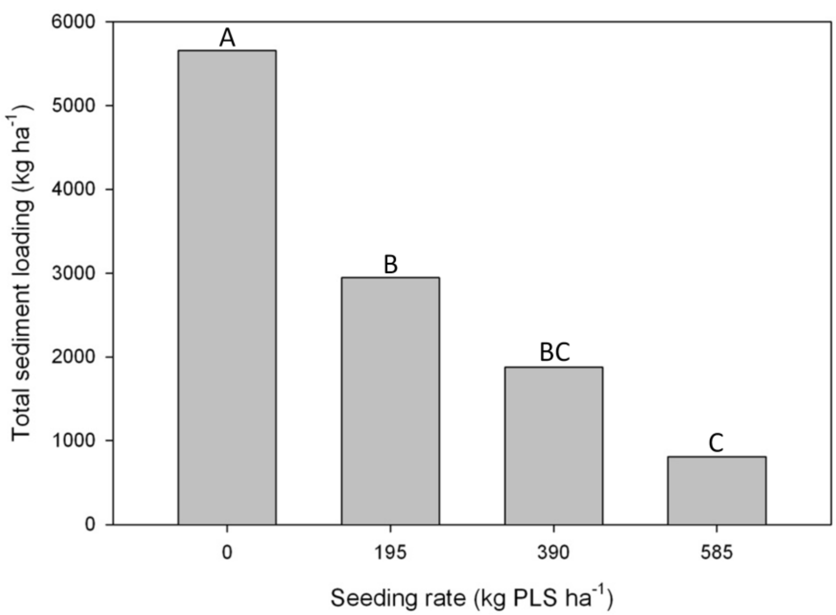

Figure 9. Total sediment loading from three rainfall simulations conducted 14, 28, and 42 days after seeding on perennial ryegrass swards seeded at 0, 195, 390, or 585 kg ha^{-1}. Sediment loading means are separated by rainfall simulation date using Fisher Protected LSD $_{(\alpha=0.05)}$.

Discussion

For earthen embankments subject to intense and frequent rainfall that results in surface runoff, this research clearly demonstrated that higher seeding rates can accelerate PR coverage for greater erosion resistance. Based on the data from this study, increasing PR seeding rates during establishment from 195 kg ha^{-1} to 390 or 585 kg ha^{-1} can reduce total sediment loading 48% to 67% and 86% eroded from bare soil, respectively. Grasses create a dense canopy that increases water infiltration to limit runoff occurrence and severity; reduces kinetic energy associated with splash erosion from raindrop impact; as well as filters suspended solids in flowing waters (Krenitsky et al., 1998; Easton and Petrovic, 2004; Burwell et al., 2011). Numerous studies concerning sediment erosion in agronomic fields or other environments have clearly demonstrated and described the benefits mature vegetation has to significantly decrease sediment loading compared to fallow soils (Gross et al., 1990, 1991; Krenistsky et al., 1998; Linde and Watschke, 1997; Linde et al. 1995, 1998).

The ability of higher Perennial ryegrass seeding rates to reduce sediment loading during establishment is a direct result of higher vegetative coverage decreasing erosion during the first runoff event 14 DAS. Similar to the findings of Burwell et al. (2011) in which higher sediment losses were correlated to lower groundcover with 62 to 90% of total sediment calculated to have eroded with <50% common bermudagrass groundcover during establishment, sediment lost during the initial rainfall simulation in this study accounted for 88, 93, 83, and 62% of total sediment losses during the 42-d establishment period for increasing seeding rates and bare soil control, respectively. Therefore, faster PR coverage can significantly reduce potential sediment losses within the first few weeks after seeding. In addition, once surface runoff occurs, sediment losses appear to become static within 5 min, indicating the length of the runoff period will directly affect sediment mass lost from a site and that plant cover mediates sediment detachment and movement. A slightly different relationship than has been reported for soluble pollutants such as nitrogen in which high pollutant concentrations initially occurs within the first volumes of runoff before declining with subsequent flow (Easton and Petrovic, 2004; Gaudreau et al. 2002; and Linde and Watschke, 1997).

Under suitable environmental conditions, PR can germinate in less than 7 d followed by rapid growth. Therefore, from a groundcover measurement, increasing seeding rates increased plant populations exponentially 14 DAS as demonstrated with 23, 47, and 64% ground cover for increasing perennial ryegrass seeding rates, respectively. The presence of the plant material in the form of leaves most likely shielded the soil from raindrop impact erosion and disrupted water flow to filter suspended sediment particles rather than provide an extensive rooting system to retain soil. It was observed after the first rainfall simulation, that plants were being uprooted in the 390 and 585 kg ha^{-1} PR seeding rate treatments. However, the effects of seeding rate on erosion resistance may not be consistent for more slowly germinating or establishing species. For example, in a study examining tall fescue seeding rate effects on surface runoff, Gross et al. (1991) reported runoff and sediment movement did not differ across seeding rates of 0, 98, 244, 390, and 488 kg ha^{-1} but that increasing rainfall intensity from 76 to 120 mm hr^{-1} had a pronounced effect on sediment losses. Although there were differences in sward densities, Gross et al. (1991) simulated rainfall 9 months after seeding. Therefore the impact of seeding rate in terms of affect during establishment was not fully accounted and indicates differences between seeding rate effects on erosion will dissipate over time. The comparison of this study with Gross et al. (1991) demonstrates the influence species selection, period of observation, rainfall intensity, duration, and timing can have on a site's erosion resistance performance.

Taking into account the high rainfall intensity and frequency employed in this study, the data clearly indicates increasing PR seeding rates can potentially reduce sediment movement as a direct result of faster canopy coverage during the first few weeks following seeding. Because vegetative cover affects surface runoff severity, assessing certain vegetal parameters may provide greater insight into how grasses reduce erosion during the initial weeks after establishment. Data characterizing PR coverage and tiller density in this study indicating increasing PR seeding rate accelerated turfgrass coverage and early tiller density 14 DAS. Easton and Petrovic (2004) positively correlated Kentucky bluegrass tiller density to runoff initiation in a study examining nitrogen effects on Kentucky bluegrass (*Poa pratensis* L.) surface runoff. They reported increasing tiller density resulted in greater runoff resistance due to increased infiltration and reduced runoff volumes. In this study PR ground cover was a simple measurement that confirmed the findings of Burwell et al. (2011) who illustrated a negative linear relationship between sediment losses and grass coverage. The fluctuations in tiller density between rainfall events from 14 DAS to 28 DAS are the result of plant damage from intense rainfall and water flow. Flowing water was observed to uproot immature plants that later desiccated and died prior to the subsequent simulation 28 DAS. Changes in tiller density would alter intra-sward competition as well as be affected by delayed PR seed germination. Changes in ryegrass sward architecture from higher seeding rates has been reported in dormant warm-season overseeding studies (Green et al., 2004; Nelson et al., 2005; Trappe et al., 2012). Therefore, tiller counts may be a better gauge for describing runoff potential for more mature grass swards rather than during establishment; this also indicates canopy coverage regardless of tiller density is more of a significant factor when describing erosion dynamics in the initial weeks of establishment.

Long-term runoff resistance and performance differences between PR seeding rates would not be expected once higher vegetative coverages are achieved. At 42 DAS each PR seeding rate resulted in >80% ground cover with < 103 kg soil ha^{-1} lost in the final runoff simulation. Although this study does not take into account practices such as nitrogen fertility or mulch applications at seeding, data from this study clearly demonstrated higher initial vegetative coverage as result of increasing PR seeding rates provides an alternative method to reduce sediment loading without relying on soluble nutrients prone to movement for canopy closure. Of course the application of mulches could alter erosion losses especially prior to germination. Less fertile soils could also impact seed growth over time. However, increasing the PR seeding rate is a simple, economical, one-step process that requires basic equipment and knowledge that can significantly decrease erosion of sloped sites prone to surface runoff during late autumn through winter in the southeastern United States until a permanent warm-season species can be established.

Literature Cited

Bowman, D.C., C.T. Cherney, and T.W. Rufty, Jr. 2002. Fate and transport of nitrogen applied to six warm-season turfgrasses. Crop. Sci. 42:833-841.

Burwell, R.W.; J.S. Beasley, L.A. Gaston, S.M. Borst, R.E. Sheffield, R.E. Strahan, and G.C. Munshaw. 2011. Losses of surface runoff, total solids, and nitrogen during bermudagrass establishment on levee embankments. J. Environ. Qual. 40: 1241-1248.

Daniel, T.C., P.E. McGuire, D. Stoffel, and B. Miller. 1979. TS and nutrient yield from residential construction sites. J. Environ. Qual. 8(3):304-308.

Easton, Z.M. and A.M. Petrovic. 2004. Fertilizer source effect on ground and surface water quality in drainage from turfgrass. J. Envrion. Qual. 33:645-655.

Emmons, Robert D. 1995. Turfgrass Science and Management: Second edition. Delmar Publishers. Albany, NY. 69-72.

Gaudreau, J.E., D.M. Vietor, R.H. White, T.L. Provin, and C.L. Munster. 2002. Response of turf and quality of water runoff to manure and fertilizer. J. Environ. Qual. 31:1316-1322.

Green, R.L., G.J. Klein, F. Merino, V. Gibeault 2004. Influence of fall-applied treatments on spring transition of an overseeded bermudagrass green. HortScience 39:424-428.

Gross, C.M., J.S. Angle, and M.S. Welterlen. 1990. Nutrient and sediment losses from turfgrass. J. Environ. Qual. 19:663-668.

Gross, C.M., J.S. Angle, R.L. Hill, and M.S. Welterlen. 1991. Runoff and sediment losses from tall fescue under simulated rainfall. J. Environ. Qual. 20:604-607.

Humphry, J.B., T.C. Daniel, D.R. Edwards, and A.N. Sharpley. 2002. A portable rainfall simulator for plot-scale runoff studies. Applied Engineering in Agriculture. 18:199-204.

Krenitsky, E.C., M.J. Carroll, R.L. Hill, and J.M. Krouse. 1998. Runoff and sediment losses from natural and man-made erosion control materials. Crop Sci. 38: 176-182.

Kuo, C.Y., K.A. Cave, and G.V. Loganathan. 1988. Planning of urban best management practices. Water Res. Bull. 24(1):125-132.

LDEQ, 2011. Louisiana Nonpoint Source Management Plan 2011-2016. p. 109 http://nonpoint.deq.state.la.us/wqa/NPSManagementPlan.pdf

Linde, D.T., T.L. Watschke, and A.R. Jarrett. 1998. Surface runoff comparison between creeping bentgrass and perennial ryegrass turf. J. Turfgrass Manage. 2:11-33.

Linde, D.T., T.L. Watschke, A.R. Jarrett, and J.A. Borger. 1995. Surface runoff assessment from creeping bentgrass and perennial ryegrass turf. Agron. J. 87:176-182.

Linde, D.T., and T.L. Watschke. 1997. Nutrients and sediment in runoff form creeping bentgrass and perennial ryegrass turfs. J. Environ. Qual. 26:1248-1254.

Louisiana Office of State Climatology. 2011. Around-the-State Climate Information - New Orleans/MSY. Louisiana State University Department of Geography and Anthropology. Accessed online 15 July. 2010. <http://www.losc.lsu.edu>.

Miller, W.P. (1987) A solenoid-operated, variable intensity rainfall simulator. Soil Science Society of America Journal. 51: 832-834.

Morton, T.G., A.J. Gold, and W.M. Sullivan. 1988. Influence of over-watering and fertilization on nitrogen losses from home lawns. J. Enviorn. Qual. 17: 124-130.

Nelson, L.P., J. Crowder, H.B. Pemberton 2005. Performance and transition date of a turf-type annual ryegrass in comparison to perennial ryegrass and fine fescues. Hort Technology 15: 304-308.

Pearce, R.A., M.J. Trlica, W.C. Leininger, J.L. Smith, G.W. Frasier. 1997. Efficiency of grass buffer strips and vegetation height on sediment filtration in laboratory rainfall simulations. J. Environ. Qual. 26: 139-144.

SAS Institute. 2008. Base SAS 9.1.3 procedures guide. SAS Institute, Cary, NC.

Schuler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Dept. of Environ. Programs. Washington Metropolitan Water Resources Planning Board, Washington, D.C.

Trappe, J.M., M.D. Richardson, A.J. Patton 2012. Species selection, pre-plant cultivation, and traffic affect overseeding establishment in bermudagrass turf. Agronomy Journal 104: 1130-1135.

Turgeon, A.J. 2011. Turfgrass Management: Ninth edition. Pearson Education, Inc. Upper Saddle River, NJ. 82-84; 320-328

USDA. 2008. National research project for simulated rainfall – surface runoff studies Protocol. USDA National Phosphorus Research Project. USDA, University Park, Pennsylvania. pp. 17. accessed online 22 Feb. 2011. <http://www.ars.usda.gov>.

USEPA. 1976. Quality criteria for water. USEPA Rep. 440/9-76-023. U.S. Gov. Print. Office, Washington, D.C.

USEPA. 1983. Reducing runoff pollution using vegetated borderland for manure application sites. EPA-600/52-83-022. USEPA, Washington, D.C., pp. 72.

USEPA (U.S. Environmental Protection Agency). 1999. Method 160.2: Total Suspended Solids (TSS) (Gravimetric, Dried at 103-105oC); U.S. Environmental Protection Agency: Washington, D.C. Revised November 1999.

USEPA. 2011. Sowing the seeds for Healthy Waterways: How your garden choices can have a positive impact in your watershed. USEPA, Washington, D.C. accessed online. 21 Mar. 2011 http://nlquery.epa.gov/epasearch/epasearch?areaname=&areasearchurl=search.html &typeofsearch=epa&search_crumbs=no&result_template=epafiles_default.xsl&allquery =phosphorus+fertilizer+bans&allin=&phrasequery=&phrasein=&anyquery=&anyin=&nonequery=&nonein=&doctype=all&sort=term_relevancy>

Wauchope, R.D, J.R. Young, R.B. Chalfant, L.R. Marti, H.R. Sumner. 1991. Deposition, mobility and persistence of sprinkler-irrigation-applied chlorpyrifos on corn foliage and in soil. Pesticide Science 32: 235-243.

Chapter 3: Effects of Irrigation on N Movement Post Fertilization of Perennial Ryegrass

Sediment loading and nutrient losses from surface runoff are common pollutants that impair water bodies throughout the United States (USEPA, 1999). Nitrogen contamination of surface waters via surface runoff has been shown to significantly contribute to eutrophication and subsequent deterioration of surface water quality (Sharpley et al., 1994; Uttormark et al., 1974). Researchers have reported concentrations as low as 1 mg N L^{-1} increase algal growth that in turn leads to impaired water quality (Walker and Branham, 1992; Koehler et al., 1982; Mallin and Wheeler, 2000). Therefore, management of N and P through implementation of best management practices should be a component of any fertilization plan.

Mature grass systems have been recognized and often cited for reducing nutrient and sediment movement by reducing surface runoff occurrence, severity and filtering suspended solids and adsorbed pollutants (Easton and Petrovic, 2004; Linde and Watschke, 1996; Gross et al., 1990; Daniel et al., 1979). Increased use of fertilizers to maintain grassed areas has risen over the years. However, turf managers often relying on natural rainfall to incorporate fertilizers may be increasing nutrient runoff losses. In a 2011 study, Borst found grass coverage had little impact on nutrient losses when rainfall intensity exceeded soil infiltration capacity. In fact, he concluded grass may contribute to greater nutrient losses from granular fertilizers because it was limiting fertilizer interaction with the underlying soil. He suggested fertilizer incorporation with irrigation may decrease potential nutrient movement. In 2002, Schroeder reported P losses could be curbed 12% simply by irrigating post fertilization.

As irrigation has become more available in home lawns and athletic fields, the simple act of irrigating post fertilizer application may decrease N and P losses from surface runoff. In order to test this best management practice, a study was conducted to determine how effective irrigation post fertilizer application affected N and P losses from surface runoff.

Materials and Methods

Nutrient and Sediment Loading of Established Perennial Ryegrass in Runoff Trays

The study was conducted at the Louisiana State University Agricultural Center Burden Research Facility in Baton Rouge, LA in 2011 and 2012. Twelve stainless steel trays (140 cm x 76 cm x 14 cm) within internal areas of 1 m^2 were filled and compacted using a soil consisting of 57.3% clay, 32.1% silt, and 9.8% sand collected from the Bonnet Carre Spillway borrow pit located near LaPlace, LA. Soils had pH 8.1 with fertility levels of 62.4 mg P kg^{-1} and 338.7 mg K kg^{-1}. Soil-filled trays were maintained under greenhouse conditions at 28 C and 1600 PAR. Trays were placed on wooden pallets to allow placement of trays directly under the rainfall simulator for simulation events.

The stainless steel trays (15.25 cm x 208.5 cm x 75 cm) were seeded with perennial ryegrass at 585 kg PLS ha^{-1}. Seeds were irrigated with no supplemental fertilization until grass reached full maturity 42 DAS. Four trays served as unfertilized and non-irrigated controls. Eight trays served as the fertilizer treatments and were applied with a water-soluble N source, ammonium nitrate (13-13-13) at 50 kg ha^{-1}. Four trays served as irrigated treatments and four trays served as non-irrigated treatments. The irrigated fertilizer treatments were watered with 1.25 cm 48 h prior to rainfall simulations. The non-irrigated fertilizer treatments were not irrigated prior rainfall simulations.

Rainfall Simulation Setup

Thirty-minute rainfall simulations were conducted at 2 and 7 days after initial fertilizer application. The method followed for rainfall simulation was outlined by the United States

Department of Agriculture's (USDA) National Phosphorous Research Project's (NPRP) protocol for rain simulation (USDA, 2008). Trays were fixed at a 20° slope with simulated rainfall applied using the Tlaloc 3000 Rainfall Simulator (Joern's Inc.; West Lafayette, IN), a field mobile unit based on the designs of Miller (1987) and Humphry et al. (2002). The Tlaloc 3000 contains a Spraying Systems Co. Fulljet ½HH SS 50WSQ nozzle with a spray angle of 104° (±5%) that delivered 16.3 L per minute at 7 psi (USDA, 2008). The rainfall intensity selected for simulations represents a 10-year historical high for Baton Rouge, LA (Louisiana Office of State Climatology, 2010). All water used for rainfall simulations was from a municipal source. Because rainfall simulations occurred within a greenhouse, the nozzle and associated plumbing assemblies were removed from the Tlaloc 3000 enclosure and mounted 3 m above the soil surface of the trays. Runoff collection troughs made of PVC gutter materials were assembled at the base of each tray on the down slope side. Metal sheets bent to an angle of 90° were placed inside each tray to direct runoff into PVC gutters to be collected in 48 L reservoirs and weighed.

Data Collection

Prior to rainfall simulation canopy coverage was photographed for digital analysis (Systat Software, Inc.; San Jose, CA); tiller density was assessed in a 25 cm^2; and soil moisture measured using EC-5 (Decagon Devices, Pullman, WA) probes within 30 minutes of rainfall simulation. During rainfall simulations, measurements included the time until the onset of runoff and total runoff volume. At the end of the 30-min rainfall simulation, composite water samples were collected and analyzed for sediment loading and total N and P following EPA methods 160.2 and 351.2 (USEPA, 1999).

Statistical Design

Trays were arranged in a complete randomized design with 3 replications per treatment combination. Data were analyzed using the general linear procedure in the statistical software SAS (SAS, 2008). Time until runoff, total runoff volumes, sediment loading, and nutrient loss means per rainfall simulation were separated using Fisher's protected least significant difference at $p \leq 0.05$. Sediment loading and nutrient means from the rainfall simulations were totaled and analyzed using the general linear procedure in SAS with means separated according to Fisher's protected least significant difference at $p \leq 0.05$. Data was combined across experiment because the interaction term treatment by experiment was above $p \leq 0.20$. Therefore, results are reported and discussed across experiments.

Results

Surface Runoff from Perennial Ryegrass

Surface runoff initiation and volumes differed slightly across treatments with irrigation prior to rainfall simulation having the greatest impact (table 1). Irrigated fertilizer treatments delayed runoff 140 and 247 s and released 32.9 and 38.7 L at 2 and 7 DAF, respectively, compared to runoff initiation delays of 272 and 340 s and runoff volumes of 38.5 and 31.9 L for corresponding non-irrigated fertilizer treatments. Controls delayed runoff 216 and 285 s and released 23.7 and 34.2 L of runoff for the simulations 2 and 7 DAF.

The difference in the ability of each treatment to delay runoff was most likely due to initial soil moistures but other factors such as sward density may have affected results. Initial soil moistures 2 DAF were 23.4, 28.7, and 33.0 % for control, non-irrigated fertilizer, and irrigated fertilizer. Again soil moisture prior to the second rainfall simulation 7 DAF followed a similar pattern with the irrigated fertilizer treatment exhibiting the highest soil moisture at 28.7 % compared to 25.2

Table 1. Irrigation post-fertilizer application effect on surface runoff parameters and sediment losses

	Soil Moisture (%)		Time until Runoff (seconds)		Runoff Volume (liters)		Total Sediment (kg ha^{-1})	
	2 days	7 days	2 days	7 days	2 days	7 days	2 days	7 days
Unfertilized Control	23.4 c	25.2 ab	216 b	284.5 ab	23.7 b	34.2 ab	265.9 a	29.8 b
Non-Irrigated	28.7 b	21.9 b	272 a	339.5 a	38.5 a	31.9 b	221.2 ab	30.5 b
Irrigated	33 a	28.7 a	140 c	247 b	32.9 ab	38.7 a	180.9 b	64.4 a

Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD p≤0.05.
Rainfall simulation occurred at 2 and 7 days after fertilizer applications

and 21.9 for the control and non-irrigated fertilizer treatment. Sward densities and biomass from the second experiment showed minor differences with 25,600, 22,000, 25,200 tillers ha^{-1} for non-irrigated fertilizer treatments, irrigated fertilizer treatments, and controls, respectively, and corresponding biomasses of 16.4, 16.0, and 20.8 kg ha^{-1}.

Nitrogen, Phosphorus, and Sediment Losses from Surface Runoff

Nutrient losses from surface runoff differed not only across irrigated and non-irrigated fertilizer treatments but also between nitrogen and phosphorus form. Unfertilized controls had the lowest TKN, dissolved N, and TP masses lost from surface runoff for all treatments and across each rainfall simulation (table 2). Non-irrigated fertilizer treatments resulted in the highest TKN losses of 12.3 kg N ha^{-1}, moderate dissolved N losses at 3.1 mg N ha^{-1}, and highest TP losses of 2.4 P ha^{-1} 2 DAF compared to TKN, dissolved N, and TP losses of 7.0 kg N ha^{-1}, 5.2 kg N ha^{-1}, and 2.0 kg P ha^{-1} for irrigated fertilizer treatments. Nutrient losses for all treatments from the second rainfall simulation 7 DAF declined with the exception of control TP losses that were static 0.2 kg P ha^{-1}. During the second rainfall simulation, irrigated fertilizer treatments resulted in higher dissolved N losses of 3.1 kg N ha^{-1} compared to 0.1 kg N ha^{-1} for non-irrigated treatments but similar TKN and TP losses of 0.8 kg N ha^{-1} and 0.4. kg P ha^{-1} compared to 0.9 kg N ha^{-1} and 0.2 kg P ha^{-1} lost from non-irrigated treatments.

Table 2. Irrigation post-fertilizer application effect on nutrient movement via surface runoff.

	TKN (kg ha-1)		Dissolved N (kg ha-1)		TP (kg ha-1)	
	2 days	7 days	2 days	7 days	2 days	7 days
Unfertilized Control	3.4 c	0.7 a	1.4 c	0.1 b	0.2 c	0.2 a
Non-Irrigated	12.3 a	0.9 a	3.1 b	0.1 b	2.4 a	0.2 a
Irrigated	7.0 b	0.8 a	5.2 a	3.1 a	2.0 b	0.4 a

Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD p≤0.05.
TKN = Total Kejhldahl Nitrogen; TP= Total Phosphorus
Rainfall simulation occurred at 2 and 7 days after fertilizer applications

Sediment losses followed as similar pattern exhibited by nutrient losses between rainfall simulations with declines in losses with the second rainfall simulation 7 DAF (table 1). Irrigated fertilizer treatments had the lowest sediment losses at 180.9 kg ha^{-1} compared to 221.2 and 265.9 kg ha^{-1} from non-irrigated treatments and controls, respectively. However, in the second rainfall simulation irrigated fertilizer treatments resulted in the highest sediment losses at 64.4 kg ha^{-1} compared to 30.5 and 29.8 kg ha^{-1} sediment losses for non-irrigated fertilizer treatments and controls, respectively.

Discussion

Loss of nutrients and sediment from sloped areas adjacent to water bodies or drainage are of particular concern given current water impairment conditions of many water bodies around the United States. Although grasses are recognized as being good components of buffers and often prescribed for permanent or temporary cover of fallow soils (Easton and Petrovic, 2004;

Gross et al., 1990, 1991; Linde and Watschke, 1997), sloped areas subject to N and P fertilization are susceptible to nutrient movement from surface runoff. However, if simple practices such as irrigating post fertilizer application could reduce nutrient losses from sloped areas then this could serve as a more effective best management practice to limit nutrient movement. This study was designed to understand how irrigation specifically affects N and P losses.

Durations until the onset of runoff and volumes of runoff differed across treatments with irrigated fertilizer treatments being the fastest to runoff. Application of irrigation prior to rainfall simulations in order to dissolve and infiltrate fertilizer particles into the soil would have raised initial soil moisture prior to rainfall simulations. Shuman (2004) and others (Nishat et al., 2010; Linde and Watschke, 1997) have reported increases in soil moisture is a major factor in determining a site's susceptibility to runoff occurrence. The non-irrigated fertilizer treatments and controls had slightly lower soil moistures without the additions of irrigation which extended the duration until runoff was initiated. However, once runoff was initiated the volumes lost over the 30-min runoff simulations did not correspond to times runoff were delayed. Runoff resistance of a grassed area has been shown to be influenced by vegetative parameters such as coverage and architecture. Burwell et al. (2011) illustrated an increase in grass coverage of common bermudagrass (*Cynodon dactylon* L.) correlated in reduced runoff volumes. Easton and Petrovic (2004) reported a similar finding for Kentucky bluegrass (*Poa pratensis* L.) sod production by regressing increasing sward densities to increased infiltration rates and reduced runoff volumes. Grasses can create dense mats with high biomass matrices and rooting that increase infiltration and decrease water flow to limit surface runoff severity. In this study the differences in sward densities and biomasses were slight, but probably affected runoff volumes.

Once runoff was initiated, the non-irrigated fertilizer treatments resulted in the highest TKN and TP losses with 368 and 443 % higher than losses from controls and 76 and 16.8 % higher than losses from irrigated fertilizer treatments. High nutrient losses from non-irrigated slopes compared to unfertilized controls have extensively reported in the scientific literature (Gross et al, 1990, 1991; Easton and Petrovic, 2004; Vietor et al., 2004; Burwell et al. 2011). High nutrient losses from surface runoff from the first rainfall post application are typical according to many published scientific studies (Gross et al, 1991; Easton and Petrovic, 2004; Vietor et al., 2004). Findings regarding non-irrigated fertilizer treatments from this study agree with Borst (2011), who reported more than a 2 to 3-folded increase in N and P losses from surface runoff of a dense St. Augustinegrass (*Stenotaphrum secundatum*) canopy when fertilizer was not irrigated post application (Borst, 2011). When irrigation was applied, the fertilizer particles would have dissolved and infiltrated into the soil for greater plant root uptake. However, plant uptake has been shown to account for less than 50% of the nutrients absorbed of fertilizer applied leaving excess fertilizer available for movement or other processes (Henning et al., 2009). Of course factors such as soil texture, temperature, and available soil moisture can mediate many of these processes including soil and organic matter binding, microbial use, or losses from the soil-plant system (Brady and Weil, 1996). In this case, the purpose of irrigating post fertilizer application was to allow greater plant nutrient uptake as well as to move nutrients away from the soil surface to reduce interaction with flowing surface waters. In 2002, Schroeder reported P losses could be curbed 12% simply by irrigating post fertilization. However, movement of P from surface runoff has been shown to be affected strongly by current soil P concentrations and soil binding potential (Pote et al, 1996). Saturation of soil with excess P fertilization would most likely limit the effect irrigation post fertilizer application has to reduce P losses from surface runoff. Fortunately, this is probably not the case for NO_3-N, which would be subject to greater leaching especially as soil hydraulic conductivity increased. Intense irrigation and rainfall have been shown to greatly enhance potential N leaching (Mallin and Wheeler, 2000; Easton and Petrovic, 2004; Linde et al. 1995, 1998; Linde and Watschke, 1997; Gross et al. 1990, 1991).

Interestingly, even though irrigation post fertilizer application resulted in 76 and 16.8 % reduction in TKN and TP, dissolved N losses actually increased 68% for irrigated fertilizer treatments compared to non-irrigated fertilizer treatments. This suggests that even though fertilizer particles can be dissolved, the volume of water needed to move nutrients beyond the zone of interaction with runoff waters will be dependent on soil texture and infiltration rate. Therefore, the act of simply irrigating fertilizer may not be enough to prevent nutrient losses via surface runoff. Either the combination of time between fertilization and irrigation prior to a potential rainfall should be increased to allow for plant uptake and soil processes to use available nutrient as well as allow the soil moisture reduce and/or the volume of irrigation applied should be sufficient to move nutrients away from the zone of interaction with flowing surface runoff waters. Greater attention to devising irrigation strategies to limit nutrient movement from surface runoff must be considered to maximize reduction of an area's nutrient losses.

Literature Cited

Brady, N.C., R.R. Weil 1996. The Nature and Properties of Soils: Eleventh Edition. Prentice-Hall, Inc. Upper Saddle River, NJ. 401-431; 445-472.

Borst, S.M. 2011. Influence of turfgrass coverage on nutrient and pesticide transport as affected by water and sediment displacement during surface runoff. Dissertation. Louisiana State University, Baton Rouge, Louisiana.

Burwell, R.W.; J.S. Beasley, L.A. Gaston, S.M. Borst, R.E. Sheffield, R.E. Strahan, and G.C. Munshaw. 2011. Losses of surface runoff, total solids, and nitrogen during bermudagrass establishment on levee embankments. J. Environ. Qual. 40: 1241-

1248.Daniel, T.C., P.E. McGuire, D. Stoffel, and B. Miller. 1979. TS and nutrient yield from residential construction sites. J. Environ. Qual. 8(3):304-308.

Easton, Z.M. and A.M. Petrovic. 2004. Fertilizer source effect on ground and surface water quality in drainage from turfgrass. J. Environ. Qual. 33:645-655.

Gross, C.M., J.S. Angle, R.L. Hill, and M.S. Welterlen. 1991. Runoff and TS from tall fescue under simulated rainfall. J. Environ. Qual. 20(3):604-607.

Gross, C.M., J.S. Angle, and M.S. Welterlen. 1990. Nutrient and TS from turfgrass. J. Environ. Qual. 19(4):663-668.

Henning, S., B. Branham, and R. Mulvaney. 2009. Foliar nitrogen uptake effi ciency of creeping bentgrass as aff ected by spray volume, adjuvants, tank-mixing, and fertilizer formulation. In 2009 annual meeting abstracts. ASA, CSSA, and SSSA, Madison, WI.

Humphry, J.B., T.C. Daniel, D.R. Edwards, and A.N. Sharpley. 2002. A portable rainfall simulator for plot-scale runoff studies. Applied Engineering in Agriculture. 18:199-204.

Koehler, F.A., F.J. Humenik, D.D. Johnson, J.M. Kreglow, S.A. Dressing, and R.P. Maas. 1982. Best management practices for agricultural nonpoint source control: II. Commercial fertilizer. USDA Coop. Agree. 12-05-300-472. USEPA Interagency Agree. AD-12-F-0-037-0. North Carolina Agric. Ext. Serv., Raleigh, NC.

Linde, D.T. and T.L. Watschke. 1997. Nutrients and TS in runoff from creeping bentgrass and perennial ryegrass turfs. J. Environ. Qual. 26:1248-1254.

Linde, D.T., T.L. Watschke, and A.R. Jarrett. 1998. Surface runoff comparison between creeping bentgrass and perennial ryegrass turf. J. Turfgrass Manage. 2:11-33.

Linde, D.T., T.L. Watschke, A.R. Jarrett, and J.A. Borger. 1995. Surface runoff assessment from creeping bentgrass and perennial ryegrass turf. Agron. J. 87:176-182.

Mallin, M.A. and T.L. Wheeler. 2000. Nutrient and fecal coliform discharge from coastal North Carolina golf courses. J. Environ. Qual. 29:979-986.

Miller, W.P. (1987) A solenoid-operated, variable intensity rainfall simulator. Soil Science Society of America Journal. 51: 832-834.

Nishat, S., Y. Guo, B.W. Baetz. 2010. Antecedent soil moisture conditions of different soil types in south-western Ontario, Canada. Hydrological Processes 24: 2417-2424.

Pote, D.H., T.C. Daniel, A.N. Sharpley, P.A. Moore, Jr., D.R. Edwards, and D.J. Nichols. 1996. Relating extractable phosphorus to phosphorus losses in runoff . Soil Sci. Soc. Am. J. 60:855–859.

SAS Institute. 2008. Base SAS 9.1.3 procedures guide. SAS Institute, Cary, NC.

Schroeder, P.D. 2002. Phosphorus loss in runoff from grasslands related to soil test phosphorus and poultry litter application. Thesis. University of Georgia, Athens, Georgia.

Sharpley, A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel, and K.R. Reddy. 1994. Managing agricultural phosphorus for protection of surface waters: issues and options. J. Environ. Qual. 23:437-451.

Shuman, L.M. 2004. Runoff of nitrate nitrogen and phosphorus from turfgrass after watering-in. Communications in Soil Science and Plant Analysis 35: 9-24.

USDA. 2008. National research project for simulated rainfall – surface runoff studies Protocol. USDA National Phosphorus Research Project. USDA, University Park, Pennsylvania. pp. 17. accessed online 22 Feb. 2011. <http://www.ars.usda.gov>.

USEPA (U.S. Environmental Protection Agency). 1999. Method 160.2: Total Suspended Solids (TSS) (Gravimetric, Dried at 103-105oC); U.S. Environmental Protection Agency: Washington, D.C. Revised November 1999.

Uttormark, P.D., J.D. Chapin, and K.M. Green. 1974. Estimating nutrient loading of lakes from nonpoint sources. EPA-660/3-74-020. U.S. Environmental Protection Agency, Washington, D.C.

Vietor, D.M., T.L. Provin, R.H. White, and C.L. Munster. 2004. Runoff losses of phosphorus and nitrogen imported in sod or composted manure for turf establishment. J. Environ. Qual. 33:358-366.

Walker, W.J., and B. Branham. 1992. Environmental impacts of turf-grass fertilization. In Golf Course Management and Construction: Environmental Issues. Balogh, J.C. and Walker, W.J. (Eds.). Lewis Publishers, Chelsea, MI, Chapter 2.

Chapter Summaries

Chapter 1

Nutrient losses and sediment loading from surface runoff can have devastating effects to surrounding water bodies. Nutrients such as nitrogen and phosphorus have been reported as constituents leading to increases in algal growth causing eutrophication and contamination in adjacent water bodies (Mallin and Wheeler, 2000; Hay et al., 2007; Valiela et al., 1997). Structural integrity of sloped areas such as highways, levee systems and home lawns can also be affected by surface runoff via sediment loading.

Grass establishment is an economical and effective way to reduce nutrient and sediment transport. Research has shown grass establishment is an effective way to delay surface runoff ultimately reducing sediment loading and nutrient transport (Easton and Petrovic, 2004; Linde and Watschke, 1997; Gross et al., 1990; Linde et al., 1995). In 1991, Gross et al. reported a reduction in sediment losses from tall fescue (54 kg ha^{-1}) compared to losses from bare soil (519 kg ha^{-1}) during rainfall simulations. Linde et al. (1995) reported mature creeping bentgrass verdure intercepted 113% compared to bare soil.

Research has shown that turfgrass is an effective best management practice in order to reduce sediment loading and nutrient losses on sloped sites.

Chapter 2

In 2004, Easton and Petrovic identified the establishment period for vegetative cover as the most susceptible to surface runoff and sediment loading. Because PR is commonly seeded during late autumn and early spring post construction, application of higher seeding rates may prove a simple method for reducing sediment losses during surface runoff. This experiment showed trays seeded at 0, 195, 390, or 585 kg ha^{-1} with 30-min rainfall simulations performed at

16.3 L per minute at 14, 28 and 42 days after seeding reduced total sediment loading 48% to 67% and 86% of sediment eroded from bare soil over the 42-day establishment period. Sediment losses were highest during the initial rainfall simulation at 88, 93, 83, and 62% of total sediment lost from 195, 390, or 585 kg ha^{-1} and bare soil controls, respectively. Therefore increasing PR seeding rates is an effective and efficient way to establish vegetation on sloped areas to reduce surface runoff occurrence and severity.

Chapter 3

Nitrogen contamination of surface waters via surface runoff has been shown to significantly contribute to eutrophication and subsequent deterioration of surface water quality (Sharpley et al., 1994; Uttormark et al., 1974). However, mature grass systems have been recognized and often cited for reducing nutrient and sediment movement by reducing surface runoff occurrence, severity and filtering suspended solids and adsorbed pollutants (Easton and Petrovic, 2004; Linde and Watschke, 1996; Gross et al., 1990; Daniel et al., 1979). This study examined the affects irrigation incorporated fertilizers had on nutrient losses through surface runoff 2 and 7 days after fertilization (DAF). Non-irrigated fertilizer treatments resulted in the highest TKN losses of 12.3 kg N ha^{-1}, moderate dissolved N losses at 3.1 mg N ha^{-1}, and highest TP losses of 2.4 P ha^{-1} 2 DAF compared to TKN, dissolved N, and TP losses of 7.0 kg N ha^{-1}, 5.2 kg N ha^{-1}, and 2.0 kg P ha^{-1} for irrigated fertilizer treatments. During the second rainfall simulation, irrigated fertilizer treatments resulted in higher dissolved N losses of 3.1 kg N ha^{-1} compared to 0.1 kg N ha^{-1} for non-irrigated treatments but similar TKN and TP losses of 0.8 kg N ha^{-1} and 0.4. kg P ha^{-1} compared to 0.9 kg N ha^{-1} and 0.2 kg P ha^{-1} lost from non-irrigated treatments. This suggests that irrigation to incorporate fertilizers 2 days prior to a rainfall event would be a best management practice for reducing P but not necessarily DN. However, not incorporating fertilizer with irrigation has a greater effect 7 days prior to a rainfall event. This experiment reiterates the importance of timing and incorporation of fertilizer applications' effect on nutrient runoff losses prior to natural rainfall events.

Vita

Jason Robert Anderson is the youngest child of Debra and Christian Anderson. Jason graduated from Mankato West High School in 2002 and completed his Bachelor of Science degree in Sports and Urban Turfgrass Management at North Dakota State University in 2008. After working for several years at different locations across the United States, Jason enrolled in graduate school at Louisiana State University in 2010 under the direction of Dr. Jeffrey Beasley. Jason Anderson is a candidate for a Master of Science in agronomy with a research emphasis in turfgrass management.