Chapter 2. Literature Review

2.1. The Phosphorus Cycle

Phosphorus (P) is an important component of plant-animal systems. Phosphorus is important to the formation of seeds and fruit, proper root growth, and survival and growth of seedlings (Ball et al, 2002). Phosphorus aids plants in the manufacture of food by utilizing sunlight as an energy source. Phosphorus is found in the soil in plant available and sediment bound forms. Phosphorus is removed from the landscape by loss of sediment in runoff, leaching in over-applied wet soils, and plant uptake and harvest (Figure 2-1). Loss of phosphorus through leaching is of increasing concern on soils where P has been historically over-applied causing high P levels indicated by soil testing.

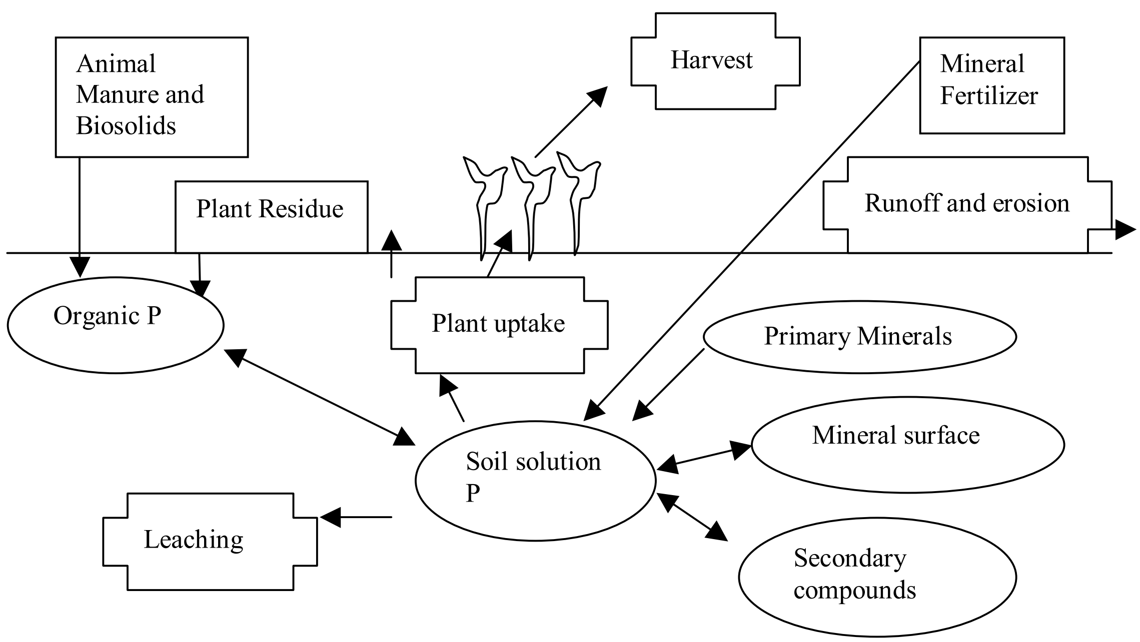

Figure 2-1: The Phosphorus Cycle

2.1.1 Soil Phosphorus

Soil P is classified into three theoretical reactive pools; soluble P, reactive P, and stable P. Orthophosphorus (ortho-P) is the most reactive and plant available form of P and makes up most of the soluble P pool. Solid phase P makes up the reactive P pool and is held in equilibrium with the soluble P pool. Reactive P is easily released to soil solution as soluble P is taken up by plants, lost in runoff, or leached from the soil (McDowell et al, 2001). Both pools are comprised of organic and inorganic forms of P. Most soil P is found in the stable P pool in a biologically unavailable form in compounds that are occluded, tightly bound to soil particles, or insoluble (Hansen et al, 2002).

Determination of soil P level is determined using soil test P (STP) methods. Four commonly used extraction methods are Bray-1 (bray and Kurtz, 1945), Olsen (Olsen et al, 1954), Mehlich-I (Nelson et al 1953), and Mehlich-III (Hansen et al, 2002, Mehlich, 1984). These methods determine amount of P available for plant growth in the soluble and reactive P pools. Degree of P saturation (DPS) in soil is determined from known soil P level and P sorption capacity soil characteristics. High levels of DPS indicate that a large percentage of the applied P remains as STP for the soil (McDowell et al, 2001). The threshold level of DPS for potential loss of P to runoff is 25 percent and addition of P at high DPS can cause desorption (Sharpley, 1995).

Sorption of soil P depends on the clay content, clay type, organic matter content, concentrations of exchangeable aluminum, iron, and calcium in the soil and soil pH (Hansen et al, 2002). Fertilizer or manure P added to soils is available to plants for only a short time and over time is lost to uptake by plants, chemical reactions to insoluble forms, or sorbtion onto mineral and organic surfaces.

2.1.2 Phosphorus in Runoff

Phosphorus lost in surface runoff is typically lost as particulate P (PP) bound to soil mineral and organic material eroded from the soil surface (Lemunyon and Daniel, 2002). Up to 60 percent of P loss from erosion is lost from PP sources. Pastureland and forest P losses in runoff are predominately ortho-P in origin. Its highly bioavailable form is easily taken up by plants and soluble in water, making it a major contributor to eutrophication. Transport of ortho-P occurs when rainfall interacts with the top 1 to 5 cm of soil and P is desorbed, dissolved or extracted from soil and plant material. High P soils have the highest potential for desorbtion of P and loss of ortho-P to runoff (Sharpley, 1995).

2.2. Conventional Dairy Management Systems and Phosphorus

Nutrient loading from dairy operations has increased tremendously since the introduction of mechanical dairy systems in the 1950s. This innovation increased the reliability and availability of mechanical feeding and milking equipment, which allowed dairy farms to transform from low-nutrient input grazing systems to high-nutrient input confinement operations (Parker et al., 1992). The adoption of confinement systems allowed dairy farms to expand herds without subsequent increases in land base because total mixed ration (TMR) feeds and corn silage, of which much is imported, replaced conventional pasture and hay forages. Dairy farm profits increased from the 1950s through the 1970s, due in part to the efficiency of the confined dairy system. However, the conditions (more animal units per acre) that increased dairy farm efficiency and profits also created a major problem: the excessive loading of N and P from animal wastes to soil.

In confinement dairy systems, nutrient surpluses were created because farm nutrient inputs, in the forms of imported feed and fertilizer, far exceeded the nutrient output of the farm production base (Erb, 2002; Rotz et al, 2001; Withers et al., 1999). The P surplus found on most confinement dairy operations can increase the potential for P enrichment in runoff from agricultural lands (Kellogg and Lander, 1999). Phosphorus losses from confinement dairies have been especially exacerbated because manure is typically land applied according to N-based NMPs (Daugherty et al, 2001).

2.3. Control Strategies for Phosphorus

2.3.1. Limiting Phosphorus Intake

Limiting P intake of animals is one of the main strategies to reduce P loading from confined dairy operations because feed is the major source of imported N and P (Erb, 2002). Most dairy producers tend to feed P at higher rates than those recommended by the National Research Council (NRC) to ensure that the P needs of cows are met with ad libitum feed uptake (NRC, 1989). Direct P supplementation accounts for 17 percent of P imports (Erb, 2002). Therefore, the National Research Council (NRC) developed new recommendations that established P levels fed to cows to a minimum based on absorbable P to reduce the amount of P imported into confined dairy operations (NRC, 2001).

2.3.2. Alternative Management Systems - Pasture

Another strategy to reduce P loading from confined dairy operations is to use pasture-based or grazing systems. Dairy farmers started to return to grazing systems in the 1980s due to the negative effects that increased environmental regulations, rising capital costs, and reduced milk prices were having on confined dairy operations (Parker et al, 1992). During the 1980s, small farms with herds of 100 or fewer cows were experiencing great financial stress due to the aforementioned factors (Kaffka, 1987). Many of these dairy farms converted to grazing systems in an attempt to lower production costs and increase farm profits (Parker et al, 1992). Additionally, these systems provided benefits of improved herd health, reduction of crop production costs, reduced capital costs, and lifestyle benefits (Gloy et al, 2002, Washburn et al, 2002, White et al, 2002).

2.3.3. Environmental Issues of Grazing Systems

Grazing systems may reduce nutrient loading to soils and NPS pollution; however, these systems have been associated with other environmental problems. Gifford and Hawkins

(1978) reported that infiltration rates of light to moderately grazed pastures were 75 percent of those in ungrazed pastures. In addition, infiltration rates in heavily grazed pastures were 50 percent of those in the ungrazed treatments.

Infiltration rates influence the amount of runoff from land in grazing as the macropore structure of the soil is lost and soil surface area is exposed due to removal of vegetation (Johnston 1962). Studies conducted by the New South Wales Soil Conservation Service indicated that mean annual soil loss was highest from moderately or heavily grazed plots than lightly grazed plots by a factor of four (Edwards, 1987). Lang and McCaffrey (1984) reported that a loss of 70 to 75 percent of ground cover is the critical level at which marked soil loss and runoff will occur from land in grazing. Further research has indicated that heavy stocking rates in rotational grazing systems are detrimental to infiltration rate and sediment production regardless of the rotation configuration and schedule used (Thurow, 1985; Warren, 1985; Weltz, 1985).

Soil hydrologic stability is another soil characteristic affected by grazing. Rest periods between grazing have a greater affect on soil hydrologic stability than intensive livestock activity (Warren et al, 1986). The potential for increasing rest periods is greatest for grazing systems with small numbers of paddocks; therefore, little benefit in soil hydrologic condition is observed with the increase of paddock numbers in rotational grazing systems.

Many studies have noted the decline of forage quality with increased grazing activity (Thurow, 1999; Dyksterhuis, 1949). Heavy continuous grazing was found to enhance growth of short-lived annual forbs with low-palatability and low forage yield during the dominant seasons when forage was at its highest rate of growth (Thurow and Hussein, 1989). Furthermore, heavy grazing was found to reduce yields of bunchgrass species when used for long-term pasture maintenance, regardless of the grazing strategy (Thurow et al, 1988).

2.4. Management Intensive Grazing and Dairy Profitability

One of the more popular pasture-based dairy systems has been the management intensive grazing (MIG) system. This system entails the rotation of grazing animals through small sections of a large pasture referred to as paddocks (Voisin, 1959). Paddock size is determined by the amount of forage dry matter available to support a given number of animals for 12 to 24 hours. After the grazing period, the paddock is allowed to "rest", which allows the forage to regrow to an optimal height and quality for grazing before the pasture is utilized again.

Many dairy producers have found pasture-based dairy systems to be profitable. A study conducted in New York State found that MIG increased farm profitability by reducing the amount of concentrated feed that needed to be purchased (Rotz et al, 2001). Similar studies conducted in Pennsylvania and Vermont indicated that MIG could prove profitable to dairy operations while improving herd health (Winsten et al, 2000) and long-term farm viability (Parker et al, 1992).

In addition to financial benefits, studies have shown that pasture-based dairy systems may reduce P loading to soils. Rotz et al. (2001) found that MIG decreased soil P accumulation. The study also indicated that although changes in cropping rotations did not significantly affect farm P balances, dairies that used MIG at levels that reduced purchased feed imports significantly changed and improved P balances. Furthermore, the rotation of lactating cows through MIG pastures was found to have the potential to achieve long-term P balances while improving grass production and utilization.

2.5. Forages

Dairy cattle require forages with the potential for high intake, digestibility, and proper balance of required nutrients (Polan, 1995). Therefore, high quality pastures with an abundance of vegetation must be provided for grazing lactating dairy cows. Producers using MIG need to identify those forages that provide the necessary high-quality yields that can support a lactating herd in order to maintain profitability.

2.5.1. Orchardgrass

Orchardgrass (*Dactylis glomerata*) is a cool-season, perennial bunchgrass. This forage is native to Europe and was introduced into the U.S. in the late 1700s (Jung and Baker, 1973). Orchardgrass grows to an average height of 2 to 3 feet from early spring until late June or early July. However, some fall production occurs from September to November (Ball et al, 2002). Orchardgrass is found from southeastern Canada to the northern areas of the Gulf States and from the Atlantic to eastern Great Plains states. This forage is well adapted to Virginia and mid-Atlantic temperature zones C and D and the upper parts of zone B (Fig. 2-3: Adaptation Zones). Studies have indicated that top growth of orchardgrass occurs at day temperatures of 21 ^{o}C with overnight temperatures of 12 ^{o}C (Baker, 1968). The rapid growth at cool temperatures makes orchardgrass especially productive in early spring and in fall in comparison to tall fescue (*Festuca arundinacea*).

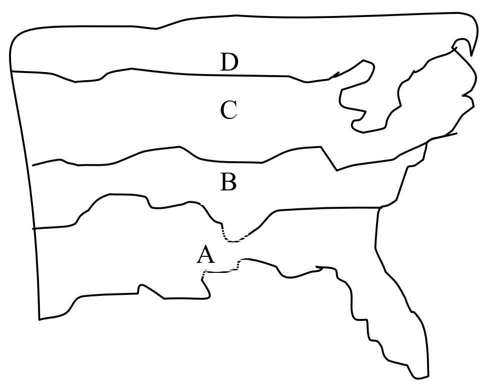

Figure 2-2: Mid-Atlantic Temperature Adaptation Zones

Orchardgrass is more heat tolerant than timothy (*Phleum pratense*), but less than tall fescue. Growth is generally suppressed at temperatures above 28 ^{o}C (Mitchell, 1983). However, orchardgrass is a shade tolerant species and will remain productive with up to 33 percent incident light interception (Pearce et al, 1965). The extensive root system of the plant provides an advantage in drought compared to timothy and Kentucky bluegrass; however, this limits the ability of orchardgrass to survive in flooded and wet soils. Orchardgrass production responds well to N fertilization and in combinations with N fixing legumes such as ladino clover. Orchardgrass requires a high level of fertility and will establish itself as the dominant pasture species when fertility is high (Henderlong et al, 1965). Seeding is recommended in August and September in all adaptive zones and in early spring in zone D and upper zone C at rates of 15 to 20 lb/acre (Ball et al, 2002). The best grazing management practice for orchardgrass is to use moderate continuous or rotational stocking of animals. The frequent removal of orchardgrass leaf tissue, typical in continuous grazing systems, weakens the plant and reduces its ability to compete with other forage species. Orchardgrass grazing is recommended when canopy height has reached 8 to12 inches; grazing should stop when canopy height is 3 to 6 inches (Ball et al, 2002). Regrowth of orchardgrass stands can occur in as little as 15 days at optimum soil, temperature, and light conditions. Typical resting periods for orchardgrass in Virginia range up to 30 days when moisture and temperature conditions are limiting to growth in summer.

2.5.2. Alfalfa

Alfalfa (*Medicago sativa*) is a cool-season, perennial legume. Native to Iran and central Asia, the forage was introduced into the U.S. in the 1730s (Ball et al., 2002; Hanson and Barnes, 1973). Alfalfa grows to an average height of 2 to 3 feet from April to October in zones B, C, and D; it has the longest productive season of the legumes adapted to the Southern U.S.

Alfalfa is considered to be the highest quality forage grown in the U.S. for hay (Barnes and Gordon, 1972). Concerns about bloat in cattle grazing on alfalfa have been addressed by the development of bloat prevention antifoaming agents, improved management recommendations, and the use of alfalfa in grass-legume mixtures (Ball et al, 2002).

Alfalfa production is highest using rotational stocking management with a rest period of 20 to 35 days. Grazing should be initiated at a canopy height of 10 to 16 inches and stopped at a height of 2 to 3 inches. In Virginia, four to six weeks of regrowth in late summer to early autumn is recommended to replenish root reserves and allows for late autumn grazing.

Alfalfa has a deep taproot, which makes it drought tolerant. The forage is sensitive to soil pH below 6.5 and needs large amounts of potassium (K). Nitrogen fertilization is not needed because of its ability to fix N. However, P, boron (B), and sulfur (S) must be supplied to produce good yields. Seeding requires a firm seedbed and can occur in August to early September in zones C and D or in February to April in upper zone B, zone C and D.

2.5.3. Red Clover

Red clover (*Trifolium pratense*) is a cool-season legume native to southeastern Europe and Turkey. The legume is either a short-lived perennial or annual (Taylor, 1973; Fergus and Hollowell, 1960). In Virginia, red clover typically persists for two years in a stand. Red clover grows to an average height of 2 to 3 feet in zones C and D and in zone B with special management. The legume is relatively drought tolerant compared to other legumes and can tolerate wetter and more acidic soils than alfalfa.

The productive season for red clover is from April to October (Ball et al, 2002). Seeding of pastures should take place in September to October at a drill rate of 6 to 8 lb/acre or 12 to 15 lb/acre if broadcast. Overseeding in established pastures should occur in October to November or February to March. Seeding vigor of red clover is the best of all the clovers. Frost seeding is a popular establishment method and involves broadcasting the seed over an established pasture in late winter or early spring. Freezing and thawing of the ground and early spring rains provide coverage for the seed and aid in establishment.

Red clover is not tolerant of continuous close grazing and should be rotationally grazed. Yields are higher than those of white clover in summer months. The legume is best utilized as a companion legume to a cool-season grass such as orchardgrass. Red clover provides the N necessary for good cool-season grass production and the grass-legume mixture has a reduced chance of causing bloat than pure clover.

2.5.4. Buckhorn Plantain

Buckhorn plantain (*Plantago lanceolatea*) is a cool-season, bunch-type weed of cultivation (Novak, 1966). The plant exhibits a strong dominance in crop fields and thinning pastures where soil exposure is high. Buckhorn plantain is an especially drought-tolerant species, making it ideal to establish in thinning alfalfa stands (CISC, 1999). New Zealand forage producers have noted the ability of buckhorn plantain to establish itself quickly and exhibit high mineral content in the forage produced. Levels of macro-minerals such as calcium, magnesium, sodium, phosphorus, and zinc are often found in the forage at levels comparable to or higher than ryegrass and white clover. Grazing trials have indicated that animals prefer the plant over most grasses when in early stages of growth; however, a sharp decline in intake occurs as the plant matures and becomes less palatable (Caddel, 2003; CISC, 1999).

2.6. Environmental Effects of Forage Production

Soil erosion is affected by the type and cover quality of the vegetation on the soil surface. Lower runoff and soil loss from alfalfa and rangeland pastures have been reported (Moldenhauer, 1987; Jones et al, 1985). Established grassland and pasture provide ample protection against soil erosion (Sturgil et al., 1990; Moldenhauer, 1987). Nitrogen and P losses in runoff and sediment were higher for cropped land uses than for alfalfa (Thomas et al, 1992). Surface sealing of soils in established alfalfa crops may increase production of runoff and promote soil loss and reduced yield (Zemenchik, 1996).

Higher infiltration rates and lower sediment losses have been reported from bunchgrasses compared to sodgrasses (Thurow et al, 1986). The presence of greater physical obstruction and litter in the bunchgrass compared to the sodgrass are the contributing factors to this phenomenon. Soil bulk density has been linked to the forage height of a pasture stand. A one-year Florida study of canopy height of limpograss (*Hermartria altissima)* indicated that bulk density significantly decreased with increased grazing height (Newman et al, 2003). Reduction in ground cover as a result of defoliation increases the susceptibility of the soil surface to erode to surface waters (Gilley et al 2002).

2.7. Summary

Dairy systems adopting MIG systems for production have the ability to increase efficiency of P utilization on farm and decrease the potential for P loss to surface waters. The key factor affecting P loss from dairies using MIG is the reduction in imported feeds brought onto the farm resulting in nutrient imports that must be disposed of on farm. Farms using MIG tend to balance land base with animal needs and waste production more effectively than larger CAFOs. The imbalance of animal units to land available to apply waste has resulted in over-applied P soils on larger CAFO operations. The importation of feed means that the nutrients in crops raised on the farm are not the only nutrients utilized by the animals on the farm, and thus a buildup of nutrients can occur and are available for loss to surface waters.

The adoption of MIG systems versus continuously grazed systems for dairies relates to forage and soil quality. Overgrazing is common in continuously grazed systems. The ability of rotational grazing allows the producer to force animals to defecate more evenly over the farm leading to more homogenous application of manure nutrients. Soils and forages do not exhibit areas in which forage quality is of markedly better nutrient quality and stand quality. Soils are more evenly trampled and infiltration is increased and runoff decreased leading to a decreased chance of P loss from runoff sediments. The higher quality of the stands can promote better utilization and uptake of P by plants which can hold P nutrients in place and prevent losses.

Profitability of small dairy farms using MIG can be improved significantly as producers move away from expenses related to manure disposal and fertilization. Producers do not have costs associated with equipment and labor related to the disposal of stored waste as the cattle apply their waste as they graze on the land. The improvement of on farm nutrient balances can reduce producer costs of applied nutrients in chemical forms as well. Reduced supplemental feed costs and the problem of disposing of the stored nutrients from these feeds are also reduced.

Limited research has been conducted to study the effects of specific forages on P uptake, infiltration of soils, and runoff losses of sediment bound P to surface waters. Studies indicate that forages with specific growth patterns should affect the loss of sediment by the manner in which the plant-soil interface is established. Forages with fibrous root systems that hold soil in place should reduce the loss of sediment bound P to surface waters. Uptake characteristics of the plant should dictate how bio-available and water soluble P is utilized by the plant and held in plant tissues. This study seeks to investigate how different forage types can affect P loss in runoff and soil levels.