

FORAGE PRODUCTION AND PHOSPHORUS PHYTOREMEDIATION IN MANURE IMPACTED SOILS

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ABSTRACT

Amounts of manure generated by concentrated animal operations often exceed the capacity of nearby limited land, and the stricter environmental regulations lead to creation of pockets of highly impacted sites within a watershed basin. Linking forage production with manure utilization can be an effective approach for addressing both the problems of manure disposal and impact reductions on water quality. In general, cropping patterns, climates, topography, and fertilization practices affect concentrations of nutrients, including N and P in runoff waters. Forage plants include diverse groups of grasses comprising legumes and various non-legumes adapted to different climatic zones, and varying soil fertility. To optimize the P remediation in impacted sites, the knowledge on P forms and soil properties is crucial. Given the possibility of productions of high quality and quantity of herbage from such impacted agricultural areas, it would be worthwhile to utilize the existing knowledge on herbage productions from differentially manured soils, and optimize the nutrient uptakes. This review tries to consolidate the available information on the potentials and limitations of pastures in phytoremediation of P in impacted soils. Such herbage productions may not only be environmentally sound due to recycling of nutrients and reductions in nutrients losses to ecologically sensitive water bodies, but also help farmers/producers to maintain their business profitably for the long-term.

INTRODUCTION

Grasslands occupy more than 4×10^8 ha in the US of which about 0.6×10^8 ha is hay and cropland pasture or improved pasture (Mays et al., 1980). It is estimated that

forages supply 65% of the nutrients consumed by dairy cattle and 75% that of beef cattle (Mays et al., 1980). Forages also constitute over 90% of the diet of sheep, goats and horses, indicating the importance of forages (Mays et al., 1980). Although forages are not as adequately fertilized as cash crops, the trend is toward increase of fertilization to maximize the herbage production. Usage of green manures or animal manures is preferred over commercial fertilizers because of increasing awareness of their impacts on environment. Moreover, increased usage of manures as soil amendments helps to recycle waste materials. However, such usage may overlook the associated hazards, e.g., over-applications and subsequent accumulations of P in soils and ultimate increase in its loss potential to aquatic systems.

In general, livestock producers face problems associated with the disposal of manures from their animal operations due to limited land, and environmental regulations. Such scenarios have created pockets of highly impacted sites within many ranches/farms, a case in point, the Lake Okeechobee Basin. The amounts of manure generated by concentrated animal operations often exceed the capacity of nearby croplands to use and retain the nutrients, thus, smaller areas receive excessive manure (Carpenter et al., 1998). Such activities have led to a build up of P along with other nutrients, and created potential hazards to water qualities. Animal manures, however, can be an effective source of nutrients for forages, consequently their applications to pastures could help substantial amounts of nutrients including N and P recycled through herbage productions. Linking forage production with manure utilization is a sound approach for addressing both the problems of manure disposal and reducing the impacts on water quality. High quantity and quality of herbage can be produced from impacted sites, although optimal

managements of the forage production and manure depend on specific local site characteristics (Newton et al., 2003).

Animal manures have been used in agricultural/crop productions for centuries (Simpson, 1991). Unlike commercial fertilizers, using manures have disadvantage of not having the right nutrient forms and/or ratios for specific crop/forage requirements. Thus, leading to accumulations of excess nutrients including N and P in soils, ultimately may cause potential hazards on water quality. As the eco-consciousness increases around the world, developments of environmentally and economically sound agricultural production systems are receiving high priority. Integrated forage production systems are environmentally friendly (Eltun et al., 2002). Perennial pastures are ideal recipients of animal manures (Edwards, 1996) because of the low cost and broadcast easiness (i.e., no need of land preparation and easier to maneuver hauling and spreading equipment). To reduce potential threats from nutrient runoffs/leaching to water quality, maximization and recycling of nutrients through forage productions may provide attractive alternative to farmers/ranchers to circumvent stiff environmental rules and regulations, especially in the region where ecologically sensitive water bodies exist, including the Lake Okeechobee Basin.

Animal manures in different forms (in solid, slurry or liquid) have been used for crop productions with variable yield responses (Powers et al., 1975), and grasses are known to remove nutrients including P from manures and soils at varying degree. Payer and Weil (1987) reported that reed canarygrass annually removed up to 45% of the total applied P. Yield response to P at relatively high N supply has also been reported for coastal bermudagrass (Welch et al., 1963) and midland bermudagrass (Taliaferro et al.,

1975). Similarly, various grasses have been used for phytoremediation of P from wastewater and animal lagoons. In general, this review tries to provide consolidated knowledge on limitations and potentials of various forages on P uptake, particularly from manure applied soils, and discussions on problems associated with water quality impairment due to P build up in manure impacted soils.

Phosphorus Accumulation in Soils and Its Impacts on Water Quality

Various animal manures including cow and poultry manures have been used to fertilize pastures in the US and around the world. Brink et al. (2001) reported that crimson clover (*T. incarnatum* L.), a temperate forage, showed a significant positive correlation between herbage weight and P uptake in pastures amended with broiler litter. Some legumes are very efficient in acquiring P from soils. *Arachis pintoi*, a forage legume, acquired 205-220% more of sparingly soluble inorganic P than the forage grass, *Brachiaria dictyoneura*, grown in acidic soils (Rao et al., 1999). They suggested that the level of inorganic P measurement in the shoot of tropical forage legumes can be an alternative technique for the evaluations of their adaptation to low P-availability in acidic soils.

In recent years, the accumulation of nutrients, especially P in soils has received a major focus in ecologically sensitive agricultural catchments because of the eutrophication it causes to surrounding water bodies. Similarly, concentrated activities such as dairy operations in farmlands have become major obstacles to reducing P inputs to watersheds. Although animal manures are usually targeted for crop/forage production, the manures often move from the targeted agricultural parcels to aquatic systems through

runoff and leaching in substantial quantities. Such scenarios may bring undesirable changes directly or indirectly both to agricultural parcels and the receiving water bodies. In general, cropping patterns, climates, topography, fertilization practices, etc., affect the concentrations of nutrients including N and P in runoff waters. Land management of highly impacted sites such as the Lake Okeechobee Basin, may have dramatic effects on P export to streams and lakes of the region.

Muir (2001) reported that kenaf grass (*Hibiscus cannabinus*) removed 10.4 and 6.8% of the equivalent P in composted dairy manure when applied, respectively, at 10 and 20 Mg ha⁻¹ yr⁻¹ (on dry weight basis), suggesting inability of the grass to prevent P build up in soils when manure was applied annually. Kingery et al. (1993) and Sharpley et al. (1998) indicated that poultry litter applied based on N requirements provides more P than required by forages, hence P accumulations in soils occur, consequently potential threats to water quality. Liu (1996) reported that soil P moved down to 40-cm soil depth, suggesting that when P exceeded requirements of forage uptake and the sorption capacity of soils, it leached down to the lower soil layers. It is known that grasses mine P from soils so that the supply of P usually has little or no effect on dry matter yield and P removal (Liu et al., 1997). On the basis of chemical fractionation data, Graetz and Nair (1995) suggested that about 80% of TP in the A horizon soils of Lake Okeechobee Basin could be considered leachable/mobile. They reported poor P retention capacities of soils from A and E horizons, but the retention was relatively higher and variable in Bh horizon depending on soil types (Myakka ≥ Immokalee > Pomello). Some soils may have high capacities to buffer P removals from soil solutions with reserve P, consequently grass grown in such soils do not show a response to applied P fertilizers (Ziadi et al., 2001).

Pastures are significant contributors of nutrients including P (95×10^3 tons yr^{-1}) to water bodies in the US (Havens and Steinman, 1994). In general, non-point sources such as agricultural runoffs are considered major sources of P to surface waters of the US. If current practices are continued, the negative impacts of non-point sources on water quality would, perhaps increase in the future. A number of measures have been taken to reduce eutrophic impacts on water quality from dairy operations. Forage production such as exporting hay from the impacted sites would reduce potentials for P loss from soils to aquatic systems, and consequent water quality impairment. Thus, studies, investigating optimal P removals by forages and reductions in P pools that are susceptible to runoff and leaching are beginning to get much needed attentions. To achieve such goals, studies of P dynamics in pasture is crucial.

Forage Productions and Phosphorus Phytoremediation

Phosphorus Requirements of Forages

Apart from N and K, P is also a major nutrient for plant, thus, sufficient supply of P is crucial for forage production. Guevara et al. (2000) reported that every kg of N applied (at rate of 25 kg N ha^{-1}) accounted for 12.4 kg increase in forage production from a rangeland, while the increase in forage production was 18.4 kg if P was also applied (at a rate of 11 kg P ha^{-1}).

It is assumed that 0.2 mg P L^{-1} in soil solution is a reasonable estimation of P intensity factor, however, the actual level varies from crop to crop as well as with the growth stage and soil characteristics related to P diffusion into plant roots. Although reported data exists on P requirements for agronomic crops, limited studies have been

conducted for establishing required threshold soil P levels for forages. Differences in efficiencies of P utilization and acquisition exist between tropical grasses and legumes (Rao et al., 1997) so do in subtropical and other grasses and legumes, as well.

Fox et al. (1974) showed that *Desmodium aparines* (a pasture legume) required 0.2 mg P L⁻¹ in soil solution during establishment, but the requirement dropped to 0.01 mg P L⁻¹ after the 2nd cut. Carvalho et al. (1994) reported 5.4 and 9.45 mg P kg⁻¹ as critical soil P level, respectively, for *Andropogon gayanus* and *Setaria sphacelata* grasses in a red-yellow clayed latosol in the 1st yr of their establishments. Vicente-Chandler (1974) reported that tropical grasses, e.g., stargrass, guineagrass and napiergrass require at least 73 kg P ha⁻¹ annually when grown in some Puerto Rican soils, and harvested at 40-60 d intervals. They also suggested that these grasses appeared to have little tendency for luxury P consumption. Kikuyugrass and pangolagrass in Hawaii, however, had dramatic positive responses to supply of P on dry matter yields (Tamimi, 1972).

In general, the P requirement is lower in fine-textured soils due to more restricted P movement than in sandy soils (Woodruff and Kamprath, 1965). Similarly, the P requirement in soil solution for optimal availability to plants is lower for soils with higher P sorption capacity ($S_{\max}$) compared to soils with the lower sorption capacity. Fox (1969) reported an optimal growth of kikuyu grass in Hawaiian soils ($S_{\max} = 200$ mg P L⁻¹) at 0.4 mg P L⁻¹ in soil solution, while the requirement was greater than 1 mg P L⁻¹ when the grass was grown in soils that had low P sorption capacity ($S_{\max} = 70$ mg P L⁻¹). Although the P requirement of plants largely depends on forage species, and soil types, it is indicative that P equilibrium status of soils is critical for the estimation of supply of P requirements for forage productions in a given region.

Soil Fertility and Phosphorus Pools

Nutrient requirements of forages depend on their abilities to mine the essential elements from soils. Forage plants include diverse groups of grasses comprising legumes and various non-legumes (annual, biennial or perennial) adapted to different climatic zones, and varying soil fertility. Unlike legumes, non-legume forages require sufficient supply of N from soils. Similarly, lime limits forage productions often in acidic soils of tropics and subtropics by affecting the utilization/availability of nutrients including P. Soils can rapidly tie up a large amount of P in relatively less bioavailable form. Phosphorus availability in soils is greatly influenced by pH, e.g., application of P in acidic soils without liming is virtually useless (Woodhouse et al. 1982). The levels of soil nutrients may be reduced slowly or remain relatively constant in continually manured soils (Kingery et al., 1993). However, intensive forage production can deplete P levels in highly impacted soils, and the process may represent a crucial component in nutrient management in pastures.

Applications of fertilizers/manures are necessary, especially to sustain herbage production as the soil fertility is depleted due to crop removals, leaching, runoff, etc, of nutrients. Forages are grown in various types of soils. Fertilizer applications need to be geared to meet requirements for optimum production of given forages in a given farm. The abilities of different forages to uptake different elements from soils vary depending on the physiological characteristics as well as the levels and forms of elements in soils, and soil characteristics. Differential amounts of P uptake by various forage species are expected, depending on the forms of P present in soils (Cihacek, 1993) and the capacities of the plants to mine the relatively stable P. Thus, to maximize P remediation in any

given impacted sites, knowledge on P forms and soil properties is crucial. Turtola and Yli-Halla (1999) indicated that surface applications of slurry and mineral fertilizers in soils with low levels of P may significantly increase P level in the soil surface. Hence P loading to the surface runoff could increase sharply. Various practices such as tandem disk operation in pastures prior to manure application, however, may help to reduce runoff P losses (Osei et al., 2003).



Impacted soils such as in high cattle density areas often have accumulations of high amounts of mobile P. Graetz et al. (1999) showed that an average of 3.4% of TP (TP ranged from 750 to 2500 mg kg⁻¹) was of water soluble P in some of the Lake Okeechobee Basin soils. Stanley and Rhoads (2000) reported that bahiagrass did not respond if the soil test P was >16 mg P kg⁻¹ soil, and 39 mg P kg⁻¹ soil was sufficient for 2 years, however, N application increased P uptake by the bahiagrass. Bailey et al. (2000) suggested that Olsen soil-P test could provide erroneous assessment of forage/plant available P in iron-rich soils. Although there is no fool proof method for the determination of P availability in soils, relatively suitable methods should be used to estimate P availability in given soils. Proper estimations of P requirements can only be possible if existing availability in soils is measured, and it is critical to reduce P losses to runoff due to over fertilization.

Phosphorus Uptake Potential of Forages

Phosphorus plays an important role in plant growth and energy transfer at cellular level. It is probably one of the most universally applied nutrients to forage crops. Abe and Ozaki (1998) reported that the annual ryegrass had the highest P and N removal rates

among 11 spring-grown species in plant beds used to filter wastewater. Similarly, Lucero et al. (1995) and Vervoort et al. (1998) reported that plant N and P uptake increased with the rates of poultry litter application on bluegrass (*Poa pratensis* L.)-tall fescue and bermudagrass-tall fescue pastures. Robinson (1996) reported that yield and nutrient uptake had a typical positive correlation in hybrid bermudagrass pasture.

Day length and temperature requirements affect optimal growth of bermudagrass in summer (Ball et al., 1991). Although in early spring, favorable moisture conditions would help growth of forages like bermudagrass, Sharpley et al. (1994) indicated that nutrients including P could be lost in runoff from a pasture applied with broiler litter if the litter applied during the period (i.e., early spring). Similarly, Pant and Warman (2000) indicated that applying manure to timothy pasture of a cooler climatic zone (N.S., Canada) in summer would be better than early spring to reduce P loss to runoff as well as for the utilization of native soil P. Brinson et al. (1994) and Daniel et al. (1998) suggested that litter applied in summer maybe utilized by optimum growth of grasses (because of favorable temperature for growth), however, N could be lost because of NH_3 volatilization. Brink et al. (2002), however, reported that P uptake was not affected by timing of broiler litter application in bermudagrass pasture possibly due to higher than required levels of P in soils. It is apparent that depending on the bioavailability of P in soils, the timing of manure applications could be crucial for the utilization of nutrients including P by forages.

Sanderson et al. (2001) reported that “Alamo” switchgrass (*Panicum virgatum*) reduced the concentration of soluble reactive P in surface runoff at an average of 47% from the filter-strip receiving dairy manure on 150 kg N ha^{-1} basis. Sanderson and Jones

(1997) found that when large amounts of dairy manure were applied to bermudagrass [*Cynodon dactylon* (L.) Pers.]-wheat [*Triticum aestivum* (L.)] pasture, up to 20% of the equivalent manure P was removed in the herbage. The P utilization/uptake by grasses depends on the levels of P in soils. Once the P demands of grasses in pastures/grasslands are met, the efficiencies of grasses in removing/utilizing P usually decrease drastically. Banszki (1998) indicated that at 25 kg P ha⁻¹ yr⁻¹ application rate, grasses removed 77-81% of applied P, while that was at 29-32% as the application rate increased to 100 kg P ha⁻¹ yr⁻¹.

Different grasses have variable capacities to remove nutrients. Gangbazo et al. (1999) indicated greater accumulations of P and NO₃-N in soils under corn silage than timothy-red and white clover mixture. Belanger et al. (2002) reported variations among timothy genotypes on tissue P concentrations and its uptake. Newton et al. (2003) indicated that grasses tended to outperform broadleaf forages in dry matter yields and nutrient uptakes when dairy manure was applied. Bermudagrass is known to have high yield and tissue N and P concentrations in response to applied N (Brink et al., 2003; Newton et al., 2003). Belonging to the same *Cynodon* family as bermudagrass, stargrass may also accumulate substantial amounts of N and P, thus, can be a valuable forage for P phytoremediation of impacted soils. Similarly, Griffin et al. (2002) reported that nutrient removal by forage swards accounted for all applied N and almost all applied P. Although data on nutrient removals by different forages from differentially manured soils exists, it is critical to evaluate the forage species that are best suited for particular sites and conditions.

Importance of Liming and Nitrogen Fertilization

Nitrogen application is usually essential to produce high herbage yield, however, the application may alter composition of forages and soil properties in the long-term. Nitrogen often increases forage yield and N uptake by the plants (Ziadi et al., 2000). Singh (1999) indicated that application of N may increase root length and root density in grasses. Similarly, Loeppky et al. (1999) reported that N application may increase seed productions from grasses. Changes in pH due to N fertilization or lime application can greatly influence the concentration of potentially mobile P because of their effects on Al solubility (McDowell et al., 2002).



The amount of P accumulation in grasses often depends on increase in yields (Adeli and Varco, 2001). Pederson et al. (2002) suggested that improvement in N fertility would improve P concentration in forages due to its high uptake. Apart from soil characteristics and climates, plant photoperiodic response could also limit grasses response to N (Pitman and Read, 1998). It is thus apparent that soil N availability is crucial for forage production even for legumes in some instances ((Raun et al., 1999). However, maximizing N utilization efficiency is required for sustaining profitability and reducing ecological risk associated with excess residual N.

Soil pH could be lowered by prolong and/or higher N application rates (Haby et al., 1999; Singh, 1999), and ultimately affect the availability of nutrients including P (Singh, 1999). Bahiagrass can tolerate low soil fertility and acidity, while bermudagrass can tolerate moderate acidity, and is very responsive to N and P fertilization (Haby, 2002). Similarly, ryegrass is highly responsive to lime, N and P (Haby, 2002). Liming could reduce $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$ and P in some of the shallow soil layers (Malhi et al., 2002),

and consequently reduce their impacts on water quality. Moreover, lime enhances the growth of beneficial microbial population as well as reduces the Al and Mn toxicity, in other words, acts as a regulator of soil conditions (Woodhouse et al., 1982). Due to increasing N application rates, concentration of N increases in bromegrass hay, while that of P tends to decrease (Malhi et al., 2002). It is evident from these studies that liming may induce reduction in $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$ and P concentrations and increase pH in shallow soil layer as well as increase dry matter yield from bromegrass pastures. However, forages such as elephantgrass (tropical forage) could efficiently utilize P in acidic soils and grow well (Shen et al., 2001). Moreover, responses to lime and P application to Georgia-5' tall fescue (*Festuca arundinacea* Schreb.) may be greater than previously thought; Pitman (2000) reported that the grass had linear response to P application up to 80 mg kg^{-1} (soil P = 142 mg kg^{-1}), and quadratic responses to liming.

Banszki (1997) reported an increase of 38-98% in dry matter yield from grasslands in chernozem soil with supply of higher N fertilizer rates (up to $450 \text{ kg N ha}^{-1} \text{ yr}^{-1}$) compared to control. Evers (2002) reported that addition of commercial N fertilizer together with broiler litter increased the removal of P by 23% (compared to no added N) from an annual ryegrass-bermudagrass pasture. Jacobsen and Surber (1995) reported that N and P applications increased Alfalfa/grass (*Medicago sativa/Dactylic glomerata*) productions as well as the N and P concentrations in plant tissue. Sufficient supply of N is crucial for optimal forage production in many pastures. Johnson et al (2001) reported 129% increase in dry matter yields of bermudagrass, bahiagrass and stargrass by application of 78 kg N ha^{-1} per cutting compared to no N fertilization. Higher dry matter yields, however, may not always guarantee higher tissue P content (Banszki, 1997). It is

apparent that N and lime applications are very important for optimal herbage production as well as P uptake by plants. The N application, however, should be carefully estimated to avoid soil acidification.

Forage Quality and Quantity as Affected by Phosphorus Availability

Differential responses to nutrients availabilities from various forages are usually common even from the same family of grasses. Nitrogen fertilization can enhance forage yields and nutritive value such as crude protein (CP) and in-vitro organic matter digestibility (IVOMD) in buffalograss (Springer and Taliaferro, 2001). Leyshon (1991) indicated that herbage production from brome grass (*Bromus inermis* Leyss.) increased linearly in response to N fertilization of up to 200 kg N from flood irrigated medium- to heavy-textured soils (in southern Saskatchewan), however, the N application reduced tissue P content, possibly due to decrease in P availability. Adjei et al. (1999) demonstrated a need for periodic application of P along with K and micronutrients to maintain productivity from grass-legume systems in Florida. Muir (2001) found that application of composted dairy manure at 20 Mg ha⁻¹ yr⁻¹ (on dry weight basis) increased kenaf (*Hibiscus cannabinus*) yield by 25.7% by the 2nd yr of the establishment compared to control (i.e., pastures receiving no manure). A perennial Mediterranean forage legume, *Lotus glaber*, thrives in P-deficient soils and responds to small amounts of P fertilization with significant increase in yields, however, P utilization efficiency decreases with an increase in fertilization ((Torales et al., 2000). Torales, et al. (2000) also reported that *Ornithopus micranthus* showed low productivity from the P-deficient soils, and another species *Trifolium pretense* showed increased in productions with increased in P

application. Rechcigl et al. (2002) indicated that annual application of P and K may not often be necessary to improve establishment or yield of legumes [*Aeschynomene Americana* L. and *Stylosanthes guianensis* (Aubl.) SW]-bahiagrass grazed pastures on Spodosols, which have a history of P and K fertilization, and the pastures are not intensively managed. They, however, reported increase in tissue P and K due to fertilization both in the legumes and bahiagrass.

Increase in tissue P content due to increase in P fertilization rates (from 56 kg P ha⁻¹ yr⁻¹ to 112 kg P ha⁻¹ yr⁻¹) have been reported in some (Pensacola) bahiagrass (Burton et al., 1997) and rangeland grasses such as *Eriachne helmsii*, a native grass in Western Australia (Islam and Adams, 1999). Reinbott and Blevins (1997) reported that annual P fertilization (28 kg P ha⁻¹) of tall fescue pasture in soils with low P levels (Bray-1 P <18 kg ha⁻¹) increased both the herbage production in May and mineral contents in early spring. Rhoads et al. (1997), however, indicated that tissue P content in bahiagrass had no response to P application >84 kg P ha⁻¹ yr⁻¹. Nutritive values of forages are important to maintain animal operation profitably. Thus, while focusing on P removal from soils, concentrations of nutrients including P in forage tissue should be given proper consideration for sustainable phytoremediation of P impacted sites.

CONCLUSIONS

Annual removal of P by forage species can be as low as 14.6 kg ha⁻¹ (by bluegrass, *Poa annua* L.) to as high as 83 kg ha⁻¹ [by johnsongrass, *Sorghum halepense* (L.) Pers.] (Pierzynski and Logan, 1993). Utilization of forages that concentrate soil P in their tissue can contribute to optimization of P recycling within farms/ranches. Although

animal manures may not have right forms of nutrients in right ratios for specific forage requirements, they can be used as nutrients sources and recycled through herbage production. In such scenarios, combining herbage productions with manure utilizations is not a bad approach. However, such activities have led to accumulations of nutrients like P in soils of agricultural basins located in many ecologically sensitive watersheds around the world, which pose potential threats to water quality. It would be worthwhile to utilize the existing knowledge on herbage production and quality from differentially manured soils, and optimize nutrient uptake, especially of P by specific forages from a given impacted site. Such herbage production may not only be environmentally sound due to recycling of nutrients and reductions in their losses to ecologically sensitive water bodies, but also help farmers/producers to maintain economic profitability for the long-term. As there is a critical need for the understanding of P dynamics in pasture systems established in P-enriched areas, translating available information into effective policies and practices will create no losers, but both the farmers/producers and water quality lobbyists will emerge as the winners.

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