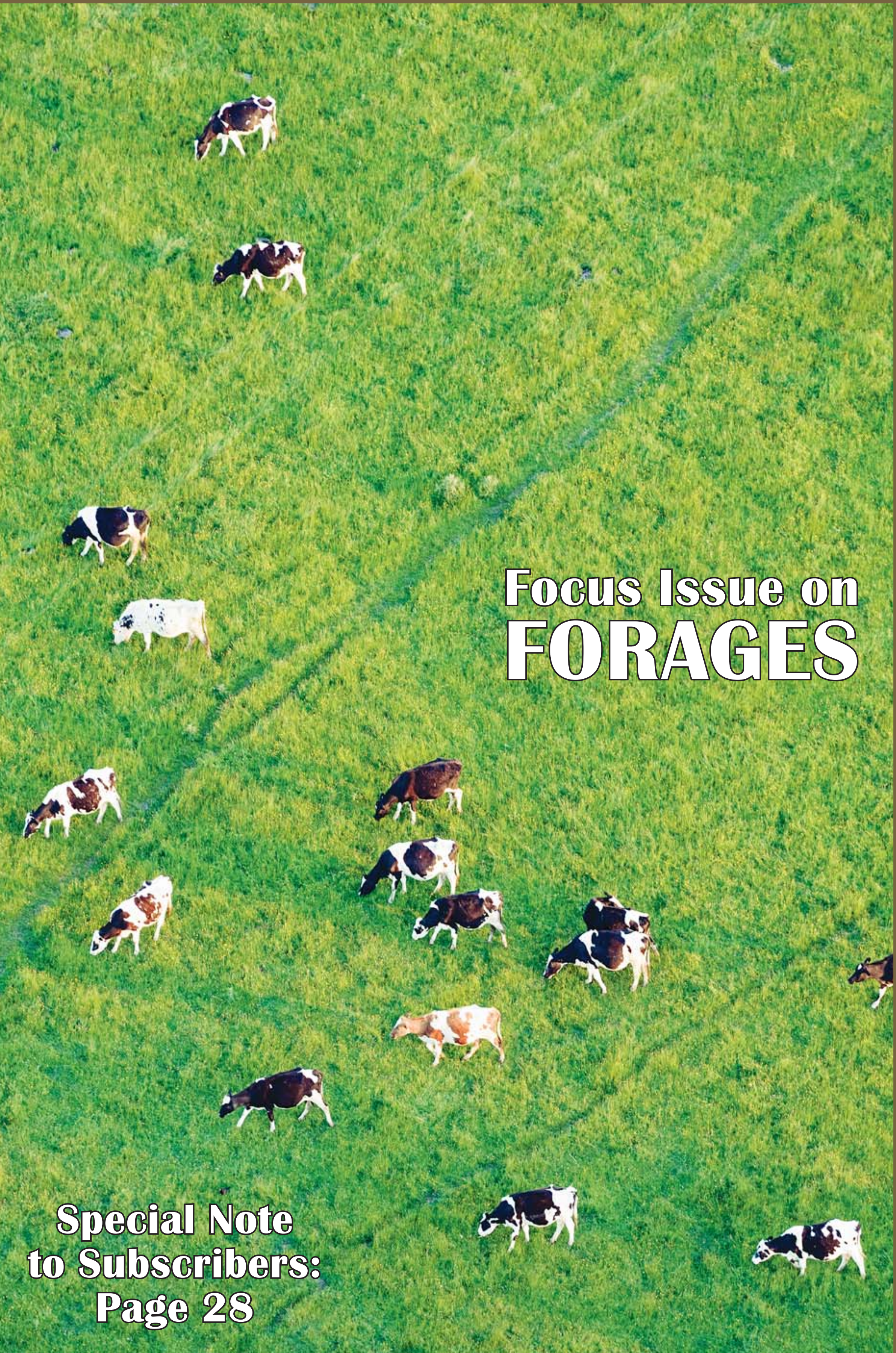
BETTER CROPS
WITH PLANT FOOD

A Publication of the International Plant Nutrition Institute (IPNI)

2017 Number 4



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Vol. CI (101) 2017, No. 4

BETTER CROPS WITH PLANT FOOD (ISSN:0006-0089) is published quarterly by IPNI. Periodicals postage paid at Peachtree Corners, GA, and at additional mailing offices (USPS 012-713). Subscriptions free on request to qualified individuals. Address changes may be e-mailed to: circulation@ipni.net

POSTMASTER: Send address changes to *Better Crops with Plant Food*, 3500 Parkway Lane, Suite 550, Peachtree Corners, GA 30092-2844. Phone (770) 447-0335; Fax (770) 448-0439. Website: www.ipni.net.

Better Crops with Plant Food is registered in Canada Post.
Publications mail agreement No. 40035026
Return undeliverable Canadian addresses to:
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IPNI thanks the Government of Saskatchewan for their support of this publication through its resource tax funding.

Fostering the Future with Forages... The Case for Pasture-Crop Rotations

By Alan J. Franzluebbers

Forages are a key component of natural resource conservation in agricultural systems.
Integration of crop and livestock systems can enhance production while preserving environmental quality.
Native warm-season grasses offer flexibility for fodder and biofuel production.

Forages are an assemblage of grasses, forbs, and legumes that have a wide variety of ecological attributes to support robust and resilient ecosystems, whether as native prairies, naturalized grasslands, managed fields, landscape plantings, or turfgrass. Forages function effectively to cycle water and nutrients, produce valuable biomass for fiber, fodder, and biofuel, and to capture energy and exchange CO_2 with the atmosphere. We do not always appreciate these ecosystem services; however, when used in conservation agricultural planning, the vital role of forages in keeping rivers and streams clean and free of nutrient and pesticide contaminants becomes readily apparent.

Forages continue to be of enormous benefit to the conservation of natural resources in agricultural systems, but there are many opportunities to expand these conservation benefits to include impacts more directly tied to production and economic outcomes.

Integrated Crop-Livestock Systems

Agriculture in industrialized countries has become increasingly specialized in response to political and economic pressures to meet market demands of an ever-larger food and fiber processing sector. For example, specialization in the USA has been accompanied by a dramatic decline in number of farms from about 6.5 million (M) in 1920 to about 2 M in 2016; but with an amazing increase in productivity. The contemporary food system in industrialized countries has become accustomed to cheap energy, an assumed stable climate, and a business environment that externalizes environmental and social costs. Unfortunately, specialized agricultural systems that simplify ecosystems and their processes can result in cumulative negative effects on the environment.

Conservation agricultural systems that integrate crops and livestock could provide opportunities to naturally capture ecological interactions, making agricultural ecosystems more efficient at cycling of nutrients, rely more on renewable natural resources, and improve the inherent functioning of soils, while achieving acceptable or improved economic returns for farmers. Although it is more ecologically efficient to consume calories and proteins from plants than from meat, livestock play an extremely important role in sustainable agricultural systems because they can utilize forages and crop residues not suitable as food and fiber for humans. Livestock also transform plant-bound nutrients into readily mineralizable substrates through passage in the rumen to improve soil fertility.

Pasture-crop rotations may be one of the most viable, but underutilized strategies to enhance soil fertility and store soil organic C in traditional cropland regions. Soil organic C often increases during pasture periods due to perennial roots that explore soil deeper and wider than many annual crops and at the same time deposit C from sloughed roots along the way. Conversely, soil organic C often declines during subsequent years when land is in crop production (García-Prechác et al., 2004). If crops were managed with no-tillage following a pasture phase, then benefits of forage on soil properties and crop production could be stronger and longer lasting. It is hypothesized that a no-tillage system of perennial forages in rotation with annual crops would lead to improved soil organic C and N contents to sustain soil fertility and enhance environmental quality. These changes in soil properties brought about by pasture-crop rotation could help meet the challenges for greater quantity and quality of food production, sustenance of human health, maintenance of wildlife diversity, and balancing of the human footprint with nature's capacity to serve our needs.

Conservation pasture-crop rotations could be a vital step in transforming agriculture from a burden on the environment to a system that produces a diversity and abundance of food crops while fortifying one of our most precious natural resources – soil. We need to consider all potential steps toward healthier soil to bridge the current dichotomy between food productivity and environmental quality. The feasibility of such rotations will of course depend on factors such as land tenure and access to livestock markets.

Maintaining productivity and enhancing soil health can be illustrated with long-term data from the Morrow Plots in Illinois, USA (Nafziger and Dunker, 2011). In this study, corn grain yield in 2- and 3-year rotations with annual and perennial forages was greater than in continuous corn production. These rotations with forages enhanced soil organic C and resulted in greater corn yield, the effect of which can be attributed to various changes in soil physical, chemical, and biological properties. Per unit change in soil organic C (g C/kg soil), corn grain yield was ~4 bu/A greater during 1905 to 1967, was 5 bu/A greater during 1968 to 1997, and was 11 bu/A greater during 1998 to 2009. Thus, in a pasture-crop rotation the likely yield increase associated with improved soil properties may help offset the grain yield sacrificed during the forage years. Furthermore, production of forage for grazing, feeding, or biofuel harvest would be additional, as well as vitally necessary to develop a healthier soil resource. These additional benefits from adoption of a conservation pasture-crop rotation will potentially be significant, as forages can be fed or sold to promote further economic gain, as well as to reduce external energy demands of the production system.

Conservation pasture-crop rotations are expected to have reduced requirements for external N inputs compared with

Abbreviations and notes: C = carbon; CO_2 = carbon dioxide; N = nitrogen; P = phosphorus; K = potassium.

Beef cattle grazing native warm-season grasses in a silvopasture (i.e., the practice of combining trees or shrubs and compatible forages on the same acreage) experiment near Goldsboro, NC.

traditional high-intensity cropping systems, because (a) conservation of N in soil organic matter usually occurs with soil C accumulation, (b) leguminous species that have biological N_2 fixation could be incorporated into pasture mixtures when possible, and (c) losses of N should be minimized through the biologically active surface soil organic matter that limits runoff, leaching, and gaseous emissions. Pastures with leguminous forages (e.g., alfalfa, clover, pea, and vetch) are highly effective in enhancing nutritive value of forages for grazing animals, as well as reducing the energy and monetary costs of N application. A key area of research that requires refinement is quantifying the contribution of soil organic N via mineralization to and from pasture and crop species in rotation sequences. A soil health tool to determine soil biological activity and its relationship to N mineralization is currently being evaluated (Franzluebbers, 2016). This soil test is now commercially available using a modified approach (see https://solvita.com/soil). If forage is mechanically harvested and removed from the field, then replacement of P, K, and other nutrients may be necessary. Additional research is needed to refine soil testing recommendations for soils varying in management history. This is especially the case for those soils being shifted from historical inputs of forage cultivation to annual cropping, and those previously degraded soils receiving a greater diversity of plant inputs from pasture-crop rotation, cover crops, and animal manure inputs.

Perennial Biofuel Production

Biofuels are a renewable energy source, because they transform energy from the sun into plant carbohydrates by taking CO_2 out of the atmosphere during production and releasing CO_2 back to the atmosphere during combustion. Assuming perennial forages can be produced with relatively low energy inputs (i.e., tractor fuel, energy embedded in nutrient applications, etc.) energy efficiency will make ligno-cellulosic biofuels from forages an attractive alternative to other biofuels. In fact, compared with corn grain, ethanol production from switchgrass emitted less greenhouse gas (0.02 vs. 0.10 g CO_2e/BTU) and yielded greater energy (49 vs. 14 M BTU/A/year; Hoefnagels et al., 2010).

A variety of perennial forages may be suitable for biofuel production. Key species to consider in many regions of the USA, particularly in the south, are those with the C4 photosynthetic pathway. Production potential is high once established and nutritional requirements are relatively low. Yearly biomass yield of four switchgrass cultivars planted at eight locations in the southeastern USA was 5.7 + 1.6 t/A (Fike et al., 2006). Production was during years 3 to 5 since establishment with annual application of 89 lb N/A, 16 to 41 lb P_2O_5/A, and 0 to 68 lb K_2O/A. On nutrient-enriched swine lagoon spray fields in eastern North Carolina, annual bermudagrass production was 2.7 t/A with nutrient removal of 85 lb N/A, 28 lb P_2O_5, and 140 lb K_2O/A (Wang, 2016). Bermudagrass has typically been grown as forage on spray fields due to its high production and nutrient removal, and value as feed for livestock. However, some alternative forages may prove even more valuable, as switchgrass produced an average of 6.4 t/A, while removing 112 lb N/A, 36 lb P_2O_5, and 232 lb K_2O/A. Respective values for giant miscanthus were 7.2 t/A, 135 lb N/A, 43 lb P_2O_5, and 201 lb K_2O/A.

Although native warm-season grasses have a reputation for difficult establishment, there are many examples of successful and productive stands occurring by the second year of establishment (Keyser et al., 2016). Research has shown that higher N fertilization and frequent hay harvest early in the growing season can produce forage with reasonably high nutritive value. Native warm-season grasses may be especially useful on marginal agricultural landscapes to increase productivity potential, as well as in combination with timber species for production as silvopasture with grazing by ruminants and/or harvested as biofuel.

Not to Forget Forages as a Key Conservation Tool

Forages provide a wealth of conservation and environmental quality benefits for improving soil health. With deep root systems and associated biological life (particularly earthworms as visual indicator), grasslands and perennial forage species improve soil structure and soil permeability, facilitate water infiltration, and help maintain soil in aerobic condition. One of the key soil characteristics of land that has been in perennial forages for decades is the high concentration of organic matter near the soil surface compared with cultivated cropland, as well as potentially greater concentrations with depth. Several studies have illustrated that whether forages are planted across an entire field or simply in strips within a field, they can significantly reduce water runoff and soil loss. Other studies have demonstrated that soil under perennial forages is enriched in organic C and N fractions, stable in structure, and inherently higher in nutrients from the stored soil organic matter. Nitrate lost from tiles draining alfalfa or conservation grassland fields is often only a fraction of the nitrate lost from fields with annual crops of corn and soybean. Diversifying crop rotations with species that have different rooting habits, using cover crops, and reducing the disturbance of surface soil with reduced or no-tillage practices can lower the intensity of nitrate production from decomposition of soil organic matter.

Closing Thought

Perennial forages should be considered an important tool in agricultural system design – not just for landscape conservation, but for enhanced production by improving soil health, promoting a stronger integration of crops and livestock to enhance system ecology, and reducing reliance on subsidy programs supporting monoculture systems.

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IPNI Staff Honored at Tri-Society Annual Meetings

Two IPNI Staff were recently given awards at the 2017 ASA-CSSA-SSSA Annual Meetings held in October at Tampa, Florida.

Dr. Terry L. Roberts was named a **Fellow of the Soil Science Society of America** (SSSA) — the highest recognition bestowed by the SSSA. Dr. Roberts is President of IPNI and a former President of the Foundation for Agronomic Research. Terry provides leadership in the global fertilizer industry on issues related to nutrient management and sustainability and oversees IPNI's global agronomic programs. Members of the SSSA nominate colleagues based on their professional achievements and meritorious service including outstanding contributions in research, teaching, extension, service, or administration and whether in public, commercial, or private service activities. Up to 0.3 percent of the Society's active and emeritus members may be elected Fellow.

Dr. Clifford S. Snyder was given the **American Society of Agronomy (ASA) Distinguished Service Award**. Dr. Snyder (retired) served as Nitrogen Program Director with IPNI, coordinating agronomic science communications and outreach to address cropping system performance and environmental issues associated with nitrogen fertilizer use in agriculture. The Distinguished Service Award recognizes individuals who have made a transformational contribution to the profession of agronomy. It recognizes development of agronomic service programs, practices, and products for acceptance by the public. The award also recognizes advances in the science, practice, and status of the profession resulting from administrative skill and effort as a member of the ASA.

Stocking Rate and Fertilization Influence Sustainability of Bermudagrass Pasture

By Monte Rouquette, Jr. and Maria Lucia Silveira

Long-term stocking of bermudagrass pastures provides for enhanced cycling of plant nutrients with minimal environmental concerns on sandy soils.

With high stocking rate, bermudagrass pasture integrity was better maintained with application of N fertilizer compared to relying solely on N fixation from clover.

Highest stocking rate pasture after 39 years of grazing. The originally planted Coastal bermudagrass has been displaced by less desirable and lower yielding bermudagrass ecotypes, as is indicated by the predominance of purple seed heads.

Lowest stocking rate pasture after 39 years of grazing. The originally planted Coastal bermudagrass remains dominant in the stand. The image shows some of the normal (brown) appearance of "pulled" stolons and leaf material that results from grazing.

Sustainable beef production is inseparably linked to sustainable forage and pasture production. In humid vegetation zones, bermudagrass [*Cynodon dactylon* (L) Pers.] is an important warm-season perennial grass for hay and pastures for cow-calf and stocker production. Bermudagrass occupies about 25 to 30 million acres in the U.S. (Taliaferro et al., 2004). Bermudagrass pastures may be overseeded with cool-season annual forages and exposed to an array of management strategies including various stocking rate and fertilization regimens (Rouquette, 2017). Early experiments with 'Coastal' bermudagrass in the 1950s and 60s determined that defoliation frequency and N fertilization rate were more important to stand maintenance than height of stubble after clipping or defoliation.

Because most soils contain limited amounts of one or more plant nutrients, pasture fertilization is an integral component of sustainable production of high quality forage. In general, soil-test results provide the basis for recommendations of P and K, while N fertilization is typically calculated based on expected yields. Although N usually has the most profound impact on forage dry matter (DM) and sustainability, P and K play an important role in pasture persistence, stand vigor, and resistance to pest and diseases.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; ppm = parts per million.

Bermudagrass removes N, P_2O_5, K_2O in an approximate ratio of 4:1:3, and early fertilizer studies suggested that a ratio of 4:1:2 may be best when using high rates of N, and ratios of 3:1:2 may be appropriate with low rates of N (Burton, 1954). The importance of K and the N:K ratio for sustainability and DM production has been well documented. Some of the most profound demonstrations of the importance of K in bermudagrass stand maintenance have involved its effect on rhizome health and survival (Keisling et al., 1979; Keisling and Rouquette, 1981), and its impact on leaf diseases (Eichhorn, 1976; Matocha and Smith, 1980).

U.S. Roundtable for Sustainable Beef

A multi-stakeholder initiative, the U.S. Roundtable for Sustainable Beef, was developed to support sustainability of the U.S. beef value chain (USRSB, 2016). A collaborative group, Global Roundtable for Sustainable Beef (GRSB, 2017) defined "sustainable beef" as a socially responsible, environmentally sound, and economically viable product. They identified natural resources as a major factor associated with sustainable beef, and included objectives such as environmental stewardship, protect grasslands from degradation, efficient management of water resources, maintain or improve soil health, and other related components.

Long-Term East Texas Study

The long-term nutrient cycling experiment reported here was conducted at Texas A&M AgriLife Research and Extension Center near Overton in east Texas. In this study both Coastal and common bermudagrass pastures have been stocked at three levels of forage mass (stocking rates) with cows and calves from 1968 to current date (Rouquette et al., 2011). Pastures have been continuously stocked during February to September each year to achieve high, medium, and low herbage mass. The study is conducted on a Darco loamy fine sand. Before study establishment, limestone was applied to correct low soil pH, and has been applied an additional nine times since.

This is a unique study in that it is one of the few (if not the only) that addresses multiple aspects of bermudagrass management and subsequent impacts on soil properties, forage production and quality, and animal performance over the course of several decades. Long-term, large-scale field trials are essential to evaluate the risks and benefits of different grazing pressure and fertilization management strategies on bermudagrass responses.

Nutrient Cycling

In grazing conditions, unlike hay production, nutrient recycling is constantly occurring, and the impact on forage mass is dependent primarily on availability of soil plant nutrients, especially N, and stocking rate (Rouquette et al., 1973). From 1968 through 1984, all pastures in the Overton study received the same annual rates of fertilizer N, P, and K in split applications. A fertility regimen x stocking rate study was initiated in 1985 to compare N + overseeded annual ryegrass (*Lolium multiflorum Lam*) versus no N + overseeded clover (*Trifolium* sp). From 1985 to 1997 no P fertilizer was applied to the experiment; however, since 1998 P has been applied annually (**Table 1**).

Table 1. Fertilizer treatments to long-term grazing study in east Texas.

Time range	Years	N	P_2O5	K_2O
		----------- lbs/A/yr -----------		
1969 to 1984	16	193	90	89
		-------- N + ryegrass --------		
1985 to 1989	5	412	0	0
1990 to 1997	8	249	0	0
1998 to 2004	7	303	104	102
		------- No N + clover -------		
1985 to 1989	5	0	0	104
1990 to 1997	8	0	0	100
1998 to 2004	7	0	104	102

Source: Rouquette and Smith (2010).

Nitrogen Fertilization and N-Fixation

Nitrogen is the nutrient most responsible for forage DM production for hay and/or grazing on the acidic, low fertility soils in the southeastern U.S. Under grazing conditions, bermudagrass overseeded with legumes without N fertilization has shown enhanced DM production (Rouquette and Smith, 2010; Han et al., 2012; Vendramini et al., 2014). Silveira et al. (2016) reported on soil properties (nitrate-N, pH, available K, Ca, and Mg) during 37 years (1968 to 2004) of stocked bermudagrass pastures at Overton. Pastures fertilized with ammonium nitrate in split-applications with annual rates averaging about 300 lb N/A had higher soil nitrate-N concentrations than non-N + clover pastures. Averaged across years, soil nitrate-N concentrations in the 0 to 6-inch depth were highest at about 14 ppm. The non-N fertilized + clover pastures were relatively constant across years at about 4 ppm and were about 72% less than N-fertilized bermudagrass.

Stocking rates did not affect soil nitrate-N levels in the 0 to 18-inch soil depth; however, high stocking rates at about 2.5 cow-calf pair per acre (1,500 lbs/pair) had less soil nitrate-N at the 18 to 48-inch depth compared to low (1 cow-calf pair/A) or medium (1.6 cow-calf pair/A) stocking rates. This is because the greater defoliation in the more intensive system (high stocking rate) required more nutrient uptake to regenerate shoot growth, resulting in less nitrate-N lower in the profile. Neither fertilization nor excreta represented a major contributor to excess soil nitrate-N during the more than 37 years stocking.

Soil Extractable K

Bermudagrass pastures receiving N fertilization but no K for 13 years (1985 to 1997) had lower soil extractable K than the no N + clover + K pastures. At the initiation of the fertility regimens imposed in fall 1984, the average soil extractable K concentration was about 48 ppm which was considered very low for bermudagrass production. These soil K levels were very low despite application of about 90 lb K_2O/A from 1968 through 1984 on the sandy Darco soil. This was likely due to the relatively low soil cation exchange capacity and limited capacity to retain K. It is possible that some K was lost via leaching and luxury consumption by the plant.

Stocking rate had no effect on soil K levels. Results suggested that nutrient cycling via animal excreta sustained soil K levels, particularly in the treatments receiving no K. Previous studies on these soils (Keisling et al., 1979; Nelson et al., 1983) at Overton showed that non-exchangeable K reserves can be efficiently converted to exchangeable forms, and in turn, represent a K source for deep-rooted bermudagrass. These pastures continue to receive 60 lb K_2O/A.

Soil P Distribution

The long-term impact of stocking and fertilization regimens on soil P distribution in overseeded bermudagrass pastures at Overton has been documented by Silveira et al. (2013). After 37 years of stocking, there was no significant effect on soil extractable P from bermudagrass fertilized with or without N. Franzluebbers et al. (2002) also showed no effect of inorganic fertilizer and clover treatments on extractable soil P. At high stocking rates, however, bermudagrass pastures receiving N had greater P concentrations in the 0 to 18-inch depth compared to pastures without N plus clover. On ungrazed plots that simulated hay production, Matocha et al. (1973) reported that P uptake by Coastal bermudagrass was enhanced by increased N rates. Bermudagrass grazed pastures that received P fertilization from 1968 through 1984 maintained plant available soil P concentrations for 13 years (1985 to 1997) without added P. Nutrient recycling via grazing and animal excreta maintained adequate soil P status for forage growth.

Our data indicated that long-term changes in extractable soil P under bermudagrass pastures were directly related to the

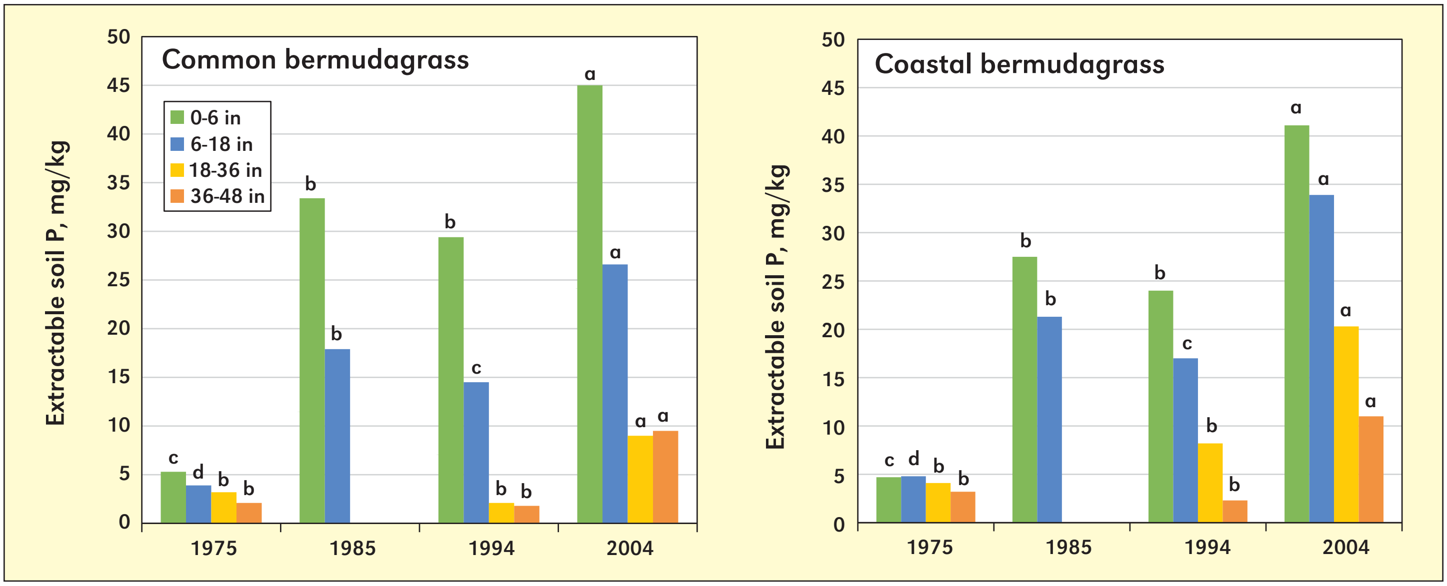

Figure 1. Changes in soil extractable P at the 0 to 48 in. depth in Common and Coastal bermudagrass pastures. Columns within series that have the same letters are not statistically different at $p \leq 0.05$.

application of P fertilizer intended to enhance soil fertility. For instance, annual application of 90 lb P_2O_5/A from 1975 to 1984 and 104 lb P_2O_5/A from 1998 to 2004 increased extractable soil P concentrations in common and Costal bermudagrass pastures (**Figure 1**). Despite the absence of P fertilization from 1985 through 1994, extractable soil P remained higher (particularly at depths >6 in.) compared to 1975 levels. Although P has been shown to be relatively immobile in the soil, on the sandy Darco soils in these pastures, P moved from the surface horizons and contributed to increased P in the subsurface depths. Ohno and Erich (1997) reported that organic acids present in animal excreta can potentially contribute to P leaching by competing with P for sorption sites in the soil. These well-managed and stocked bermudagrass pastures showed no accumulation of excessive P in soils after more than 37 years.

Bermudagrass Ecotype Diversity

After more than 38 years of continuous stocking of bermudagrass pastures during the active growth period (February to October) of overseeded cool-season annuals and bermudagrass, stands of both Coastal and common bermudagrass were negatively affected by high stocking rates, decreased herbage mass, and no N fertilization (Rouquette et al., 2011). Under low stocking rates (1 cow-calf pair/A), the originally established Coastal and common bermudagrass was still dominate, and made up about 70 to 75% of the stand (**Figures 2 and 3**). In the absence of N fertilizer (no N + clover) and under high stocking rates (2.5 cow-calf pair/A), only 20 to 27% of the original

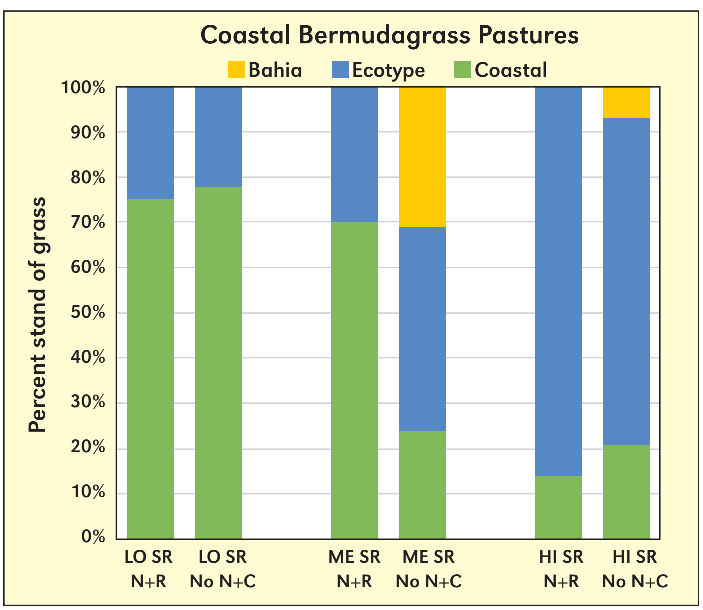

Figure 2. Invasive bermudagrass ecotypes and bahiagrass in Coastal bermudagrass pastures under long-term (>38 years) stocking rates (LO, ME, HI) and fertility regimens (N + Ryegrass vs. no N + Clover)

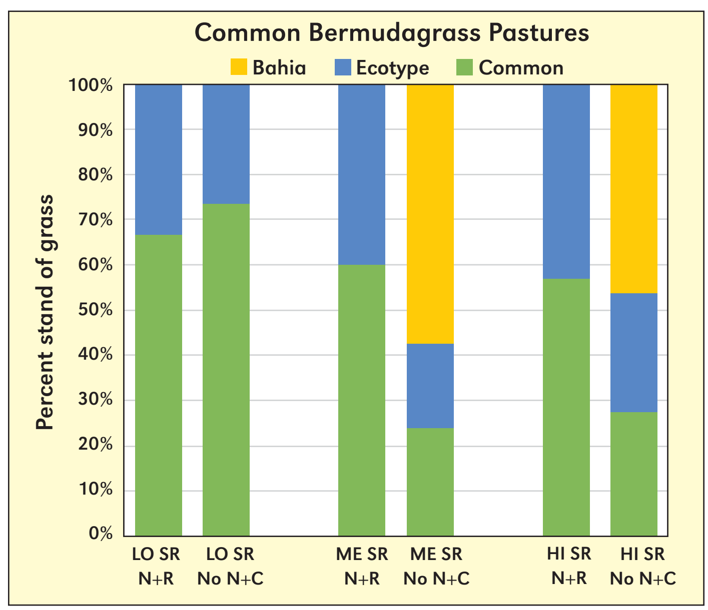

Figure 3. Invasive bermudagrass ecotypes and bahiagrass in Common bermudagrass pastures under long-term (>38 years) stocking rates (LO, ME, HI) and fertility regimens (N + Ryegrass vs. no N + Clover)

Coastal and common bermudagrass remained. In general, at the higher stocking rates the N+ryegrass treatment maintained stand integrity over time better than the no N+clover treatment.

Invading species included other bermudagrass ecotypes which maintained ground cover; thus, soil-exposed areas were minimum to non-existent (**see images**). The primary invading species on non-N fertilized common bermudagrass was bahiagrass (*Paspalum notatum* Flugge). After more than 40 years of stocking bermudagrass pastures, stocking rates of 1 cow-calf pair/A allowed for sufficient forage mass to promote stand maintenance and sustainable pastures. The high stocking rates of 2.5 cow-calf pair/A did not eradicate the invading, persistent bermudagrass ecotypes; however, these higher stocking rates during a 40-yr period practically eliminated the originally-planted, higher yielding and more desirable Coastal and common bermudagrass. The impact of long term continuous high stocking rates on bermudagrass pastures, therefore, is reduction in carrying capacity and animal gains per acre.

Conclusions

Although high stocking rates practically eliminated the original bermudagrass species, bermudagrasses are sustainable for pastures in the southeast U.S. under a wide range of less severe management strategies. This long-term grazing study documented the importance of N-fixation by clovers, which sustained bermudagrass pastures when stocked at low stocking rates of about 1 cow-calf/A. Silveira et al. (2014) summarized that recommendations for pasture fertilization are often based on soil tests; however, N fertilization rates have traditionally been based on management strategies for the desired level of dry matter yield and economic expectations. These management strategies generally do not account for residual soil N when preparing for hay and/or stocking rate.

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NPK Management for Forage Grasses in Brazil

By Eros Francisco, Gelci Carlos Lupatini, and Reges Heinrichs

Most pasture land in Brazil is inherently low in nutrients and improved soil fertility and acidity management has the potential to raise both animal performance and the efficiency of beef production.

This article reviews forage fertility management – highlighting its impact on yield, quality, and system profitability.

E. Francisco/IPNI

Well-managed pasture lands in Mato Grosso, Brazil.

Brazil's pastures currently support the world's largest commercial bovine herd, which makes the country the second largest beef producer and exporter. About 90% of livestock production in Brazil is grassland-based, but these areas are very diverse regarding technology adoption and this can have a large influence on the types of forage grown and the breeds of cattle raised. Considering Brazil's 180 million (M) ha of land in pasture and its 212 M head of cattle, the country's average stocking rate is about 1 head per hectare. In terms of land use this system can be characterized as inefficient, but it has the potential to be improved with soil amelioration to correct soil acidity and increase nutrient availability, and through the adoption of better grazing techniques.

Most of Brazil's soils are highly weathered tropical soils with low nutrient (especially P) availability, medium to high acidity (H^+ and Al^{3+}), low base saturation, and low organic matter content. The country is the fourth largest fertilizer consumer with about 34 M t of products used in 2016. However, only 1.5% of that amount is applied to pasture land, while soybeans, maize, sugarcane, coffee, and cotton consume over 80% of the total (ANDA, 2016).

Estimates are that about 50% of the pastures in the Cerrado region are considered to be degraded to some degree. Pasture degradation is mainly related to excessive grazing and crop nutrient deficiencies due to adverse soil conditions (low fertility, acidity, and compaction), leading to low biomass production and poor plant vigor. Extensive areas devoted to pastures, cultural habit of low input systems, poor access to public or private funding, misinformation, and lack of sound agronomic assistance are the main reasons for low technology adoption, including fertilizer use, by farmers. Nevertheless, some cases of success in fertilizing pastures are showing high potential for beef production, thus IPNI has promoted webinars, presentations, and demonstrations to educate farmers on the benefits of adequate use of nutrients in livestock systems and how profitable it can be.

Recommendations

Fertilizer recommendations for forage grasses in the country are based on soil analysis, species nutrient requirements, and level of technology employed. **Table1** presents a classification of grasses according to their nutrient demand.

Liming

Multiple species of *Bracharia* grass represent the majority of forages used in Brazilian pastures. Some of these grasses are tolerant of soil acidity and have relatively low nutrient requirements. Nevertheless, *Brachiaria* grasses do respond positively to liming and fertilizer application, as has been demonstrated in several studies. Liming reduces Al^{3+} toxicity, provides Ca^{2+} and Mg^{2+}, and increases nutrient use efficiency for subsequent fertilizer applications. According to Vilela et al. (2004), liming recommendations for pastures in the Cerrado region, based on soil base saturation (BS), vary according to species tolerance to soil acidity or low soil fertility: 60% BS for less tolerant grasses (group 1; **Table 1**), 50% BS for moderately tolerant grasses

Table 1. Classification of grasses according to nutrient requirement.

Group	Level of nutrient requirement	Species (cultivars)
1	High	*Panicum maximum* (Aruana, Colonião, Tanzânia, Mombaça); *Cynodon* (Coast-cross, Tifton); *Pennisetum purpureum* (Cameron, Elefante, Napier); *Digitaria decumbens* (Pangola, Transvala); *Chloris* (Rhodes)
2	Medium	*Brachiaria brizantha* (Marandu, Xaraés, Piatã); *Andropogon gayanus* (Andropogon); *Cynodon plectostachyus* (Estrelas); *Paspalum guenoarum* (Ramirez)
3	Low	*Brachiaria decumbens* (Braquiária, Ipean, Australiana); *B. humidicula* (Quicuio da Amazônia); *Paspalum notatum* (Batatais, Pensacola); *Setaria anceps* (Setária)

Source: Werner et al. (1997).

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Al = aluminum; H = hydrogen; ppm = parts per million.

Table 2. Phosphorus and potassium recommendations for the establishment and maintenance of pastures in the Cerrado, based on soil analysis and nutrient demand of plants or level of technology adoption.

Level of nutrient demand or technology adoption	Soil P[1]				Soil K		
	Very low	Low	Medium	Optimum	Low	Medium	Optimum
	P_2O_5, kg/ha[2]				K_2O, kg/ha		
	Establishment[3]						
Low (<1 AU[5]/ha)	40-120	30-90	20-60	0	20	0	0
Medium (1-3 AU/ha)	70-180	55-135	35-90	0	40	20	0
High (3-7 AU/ha)	80-240	50-150	40-120	0	60	30	0
	Maintenance[4]						
Low (<1 AU/ha)	-	15-40	0	0	40	0	0
Medium (1-3 AU/ha)	-	20-50	15-30	0	100	40	0
High (3-7 AU/ha)	-	30-60	15-40	0	200	100	0

[1] Interpretation of Mehlich 1 P availability depends on soil clay content.
[2] Rates of P_2O_5 varies according to soil clay content in direct relation.
[3] Soluble sources of P are recommended in furrow or broadcast plus incorporation. Potassium application can be broadcasted.
[4] Single broadcast application in the beginning of rainy season for P and K (<40 kg K_2O/ha). Split broadcast applications with 30-day intervals for K_2O rates >40 kg K_2O/ha.
[5] Animal unit: 454 kg cow.
Source: Vilela et al. (2004) and Cantarutti et al. (1999).

(group 2), and 35% BS for highly tolerant grasses (group 3). The authors also recommend that when the concentration of Mg^{2+} is below 0.5 $cmol_c$/kg, a dolomitic type of lime should be applied.

Another practice that may be adopted to mitigate subsoil acidity is phosphogypsum (PG) application. It reduces the degree of Al^{3+} saturation in the subsoil and provides Ca^{2+} and SO_4-S to plants. The use of PG in Brazil is common for several crops with no unacceptable risk to soil or plants (Dias et al., 2010). The criteria for PG recommendation takes into consideration the condition of the subsoil (0.2 to 0.4 m depth). Specifically, where Al^{3+} saturation is higher than 20% or Ca^{2+} is below 0.5 $cmol_c$/kg, the recommended application rate is 50 kg of PG per % of clay in the soil (Vilela et al., 2004).

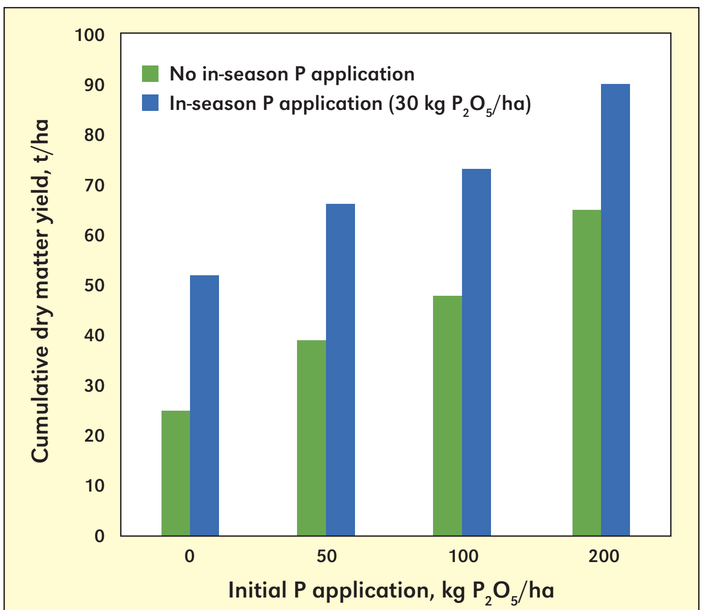

Figure 1. Cumulative dry matter yield (7 years, 16 cuttings) of *Brachiaria decumbens* in response to P application rates and levels of maintenance (no additional application versus biannual application of 30 kg P_2O_5/ha). Original soil conditions: pH (water) 4.6, P (Mehlich 1) 0.8 ppm, and Base Saturation 8%. Source: Soares et al. (2001).

Phosphorus and Potassium

Recommendations for P and K fertilizer rates in Brazil's pastures are based on the nutrient requirement of grass plus a soil analysis (**Table 2**). For grasses with low nutrient demand (group 3), fertilizer rates may vary to supply 20 to 120 kg P_2O_5/ha and up to 20 kg K_2O/ha depending on soil availability. For grasses with high nutrient demand (group 1), application rates vary from 40 to 240 kg P_2O_5/ha and up to 60 kg K_2O/ha. However, depending on the grass and level of intensification, K rates may need to be higher to support plant growth and quick recovery—up to 200 kg K_2O/ha yearly.

In Cerrado soils, P fixation is high. Therefore, liming is a best management practice (BMP) to increase soil P availability and promote its efficient use by plants. As pastures are perennial crops, P application in the seed furrow or broadcasted followed by incorporation is recommended prior to pasture establishment. For maintenance, a single broadcast application of P fertilizers (20 to 40 kg P_2O_5/ha) at the beginning of rainy season is recommended, as presented in **Figure 1**.

Soluble sources of P are recommended for their prompt availability, but phosphate rock (PR) or partial acidulated fertilizers may be an option in some regions. If PR is to be used, it is recommended that application occurs at the establishment of pastures and be incorporated into the soil. Phosphorus application is required to achieve high biomass yields in intensified livestock systems, as is shown in **Table 3**. Recommended P rates should be applied at the establishment of pastures to promote early vigorous plant growth and development of an adequate root system which leads to sustainable biomass production along with lowered risk of soil degradation.

Table 3. Dry matter yield (t/ha) of *Brachiaria decumbens* in response to N and P application rates.

	N rate, kg/ha			
P_2O_5 rate, kg/ha	0	75	150	300
0	3.35	-	-	-
60	3.39	8.14	9.95	11.8
120	3.56	8.31	12.1	15.3

Original soil conditions: pH ($CaCl_2$) 5.4, P (Resin) 5 ppm, and Base Saturation 55%. Source: Lupatini et al. (2010).

Potassium fertilizers may be broadcast on the soil surface at pasture establishment and at the beginning of rainy season (< 40 kg K_2O/ha). For maintenance of more intensive production systems demanding higher K rates, split broadcast applications in 30-day intervals are recommended. Tropical grasses require large amounts of K, which is an important nutrient to control evapotranspiration and sustain high photosynthesis performance of C4 plants. In soils low in K, plants struggle to accumulate biomass and the response to N application is compromised (**Figure 2**).

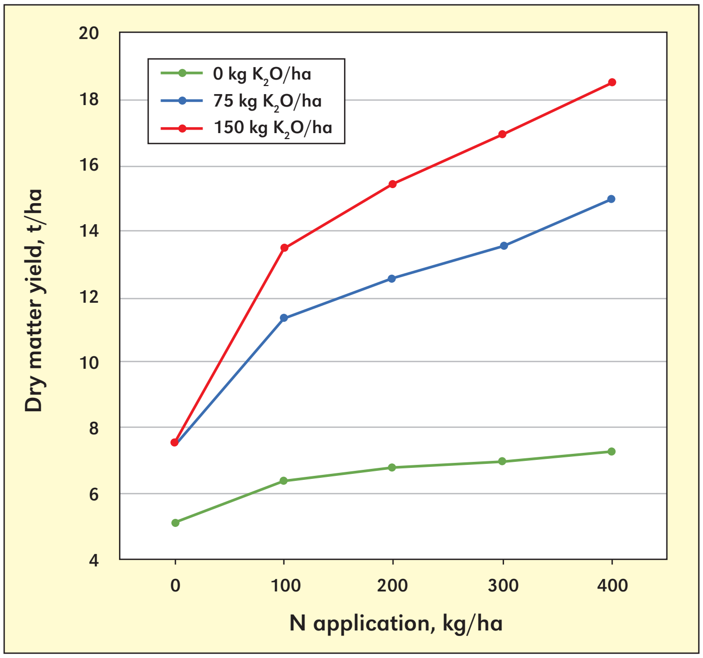

Figure 2. Cumulative dry matter yield of *Brachiaria decumbens* in response to N and K application rates. Original soil condition: pH (water) 4.6, OM 3%, and K (Mehlich 1) 42 ppm. Carvalho et al. (1991).

Nitrogen

Nitrogen is a key nutrient to promote biomass production, and C4 plants in tropical environments are very responsive to N. The recommended rate for N fertilizer will vary widely depending on soil conditions, plant demand, technology adoption by the farm, and irrigation. Vilela et al. (2004) recommend 50 kg N/ha, along with 30 kg S/ha for the establishment of pastures in the Midwest. Cantarutti et al. (1999) recommend the same amount of N and S for livestock systems using moderate technology, but 100 to 150 kg N/ha for farms using more advanced technology. For the maintenance of pastures, Vilela et al. (2004) recommend 100 to 150 kg N/ha for medium-tech farms and 200 kg N/ha in higher-tech farms. It is recommended that the higher N rates be split into three applications of at least 50 kg N/ha during the beginning, middle, and end of the rainy season. The authors encourage the use of ammonium nitrate or ammonium sulfate to avoid potential N losses due to volatilization. Urea may be used if soil and weather conditions are monitored to ensure adequate soil moisture, mild temperatures, and an application just prior to a rain if possible. For highly intensive livestock systems, N rates may also be adjusted according to other parameters (e.g., grazing efficiency, level of farm management) as is indicated in **Table 4**. Recent research

Table 4. Nitrogen requirement considering the impact of farming management on N use efficiency (NUE) and grazing harvest efficiency (GHE).

Farming management	NUE, kg DM[1]/kg N	GHE[2], %	N requirement, kg N/AU[3]
Very low	<30	<40	170
Low	30-35	40-45	130
Medium	35-40	45-50	100
High	40-45	50-55	85
Very high	45-50	55-60	70
Excellent	>50	>60	60

[1] Dry matter yield.
[2] GHE is the percent of vegetation ingested through grazing compared to the total amount of vegetation.
[3] Animal unit: 454 kg cow.
Source: Martha Junior et al. (2004).

Table 5. Dry matter accumulation rate of *Brachiaria brizantha cv. Marandu*, stocking rate, and beef yield in response to N application rates.

N rate, kg/ha	DM accumulation rate, kg/ha/day	Stocking rate, AU[1]/ha	Beef production, kg/ha
50	29.1 b[2]	2.55 b	697 b
200	51.9 a	3.44 a	863 a

[1] Animal unit: 454 kg cow.
[2] Values in each column followed by different letter are statistically different at $p = 0.05$.
Source: Gimenes et al. (2011).

studies show positive results for balanced applications of 1:1 for N:K, and 10:1 for N:S.

Complete and balanced plant nutrition and efficient grazing management are key to obtaining high yields of biomass and beef in livestock systems as shown in **Table 5**. Improving soil fertility via appropriate nutrient management is the first step for recovering degraded pastures, and increasing dry matter yield and forage quality. Certainly, the use of nutrients associated with BMPs is a profitable path for livestock farmers. BC

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Five-Step Approach to Phosphorus Use on Clover-Based Pastures

By Robert Norton and Richard Simpson

A five-step approach involves soil testing, determining stocking rates based on the soil test values and the environment, calculating maintenance and capital P requirements to meet those stocking rates, determining if the strategy is profitable, and checking to ensure other limiting factors are addressed.

R. Norton/IPNI Image

Typical pastures in the southern grazing zones (400 to 600 mm annual rainfall) would be a sub-clover (inset image) and grass sward. Dependence on legumes means that N fertilizer is not commonly used in these semi-intensive pastoral systems.

The Australian pastoral industries can be divided into nine agroclimatic zones and within each there are different levels of grazing intensification with meat and wool sheep and/or beef cattle (**Figure 1**). The temperate and Mediterranean zones vary in terms of annual rainfall and species sown and are the main regions for semi-intensive and intensive sheep and cattle grazing. Grasses such as perennial ryegrass (*Lolium perenne*), cocksfoot or orchardgrass (*Dactylis glomerata*), and phalaris (*Phalaris aquatica*) represent a grade from wetter to drier areas, and these are replaced by annual ryegrass (*Lolium rigidum*) in the annual pasture zone. The grasses are complemented in mixed pastures with perennial legumes like white clover (*Trifolium repens*) in the wetter regions and subterranean (sub-) clover (*Trifolium subterraneum*) or medics (*Medicago* spp.) in the drier regions.

The development of Australia's improved pastures (currently 37 million ha) over the past 70 years has involved the introduction of productive and nutritious species along with applications of single superphosphate (SSP). The SSP (9% P, 11% S) is typically ground or aerially spread in the autumn and/or spring, and historically rates as high as 40 kg P/ha were used on what were inherently low-P soils. Liming, top-dressed K, additional S and Mo are also often applied as needed.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Mo = molybdenum.

For legume-based pastures, legume growth and persistence is particularly responsive to P availability, and this increases the amount of biological N fixation. As a consequence, P status largely drives pasture productivity, which enables stocking rates to be raised to improve farm profitability. To assist growers in making important fertilizer decisions, many years of science and industry-based research have been combined into a "Five Easy Steps" approach for managing soil P fertility in pastures. The aim is to improve profitability by appropriate SSP use on legume-based pastures grazed by sheep and cattle. A summary of this approach is presented here, while full details, including worked examples and a spreadsheet calculator, can be obtained from Simpson et al. (2009); the booklet and a related Microsoft Excel-based decision support tool can be downloaded from the link provided in the reference list.

Step 1: Soil test to assess current fertility

There are two common soil P tests for pastures in Australia

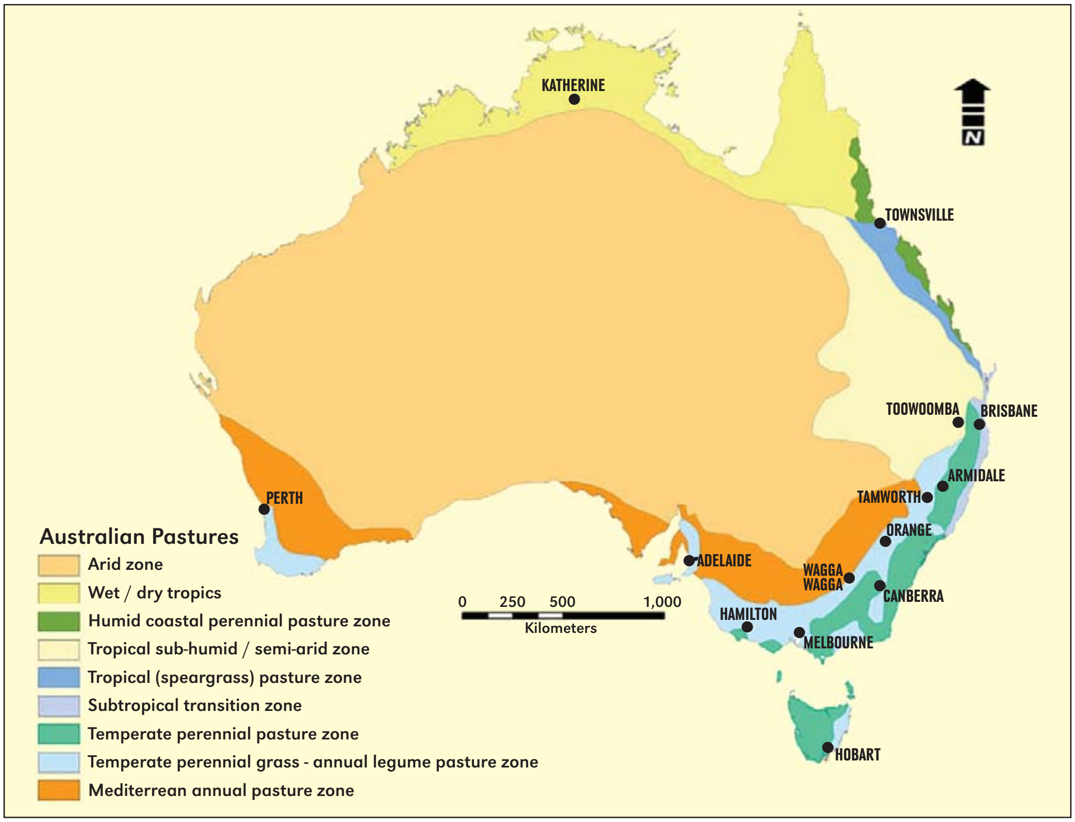

Figure 1. Pastures of Australia based on the limits to the adaptation of tropical and temperate pasture species (Wolfe, 2009).

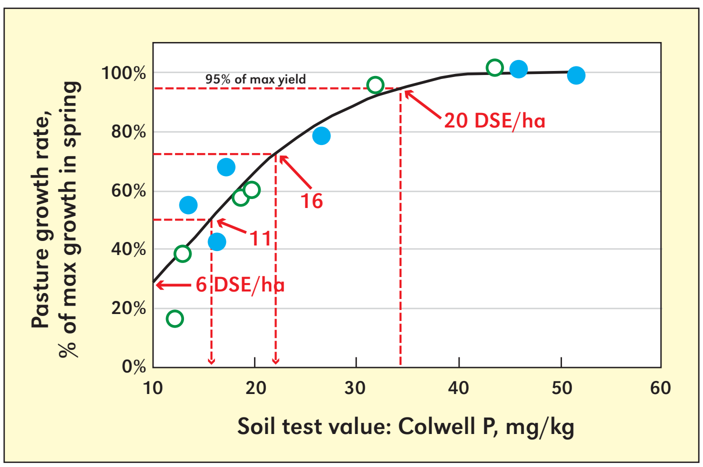

Figure 2. Combining soil P test values with pasture productivity to estimate likely stocking rates in an example where the potential carrying capacity is 20 DSE/ha. This example uses an unfertilized paddock with 6 DSE/ha and roughly equal increments in pasture yield and stocking rate with rising soil test values.

(Colwell-P and Olsen-P), both are bicarbonate extractions of different exposure times and soil solution concentrations, and each is well calibrated. A soil test value that indicates that a pasture should achieve about 95% of maximum yield is known as the "critical" soil test value. Critical values are reported as mg (extractable-P) per kg of dry soil. The critical value for the Olsen-P test is around 15 mg P/kg soil for clover-based pastures. However, the critical Colwell-P test value varies with the Phosphorus Buffering Index (PBI) of the soil. PBI is a measure of the P-sorbing capacity of the soil and it varies among soil types. A PBI of 100 indicates a critical Colwell P soil test value of around 32 mg P/kg to produce 95% of maximum pasture yield, whereas a soil with a PBI value of 200 will have a critical Colwell P soil test value of about 40 mg P/kg. The relationship between the PBI of different soils and their critical Colwell P values was determined in the Better Fertilizer Decisions for Grazed Pastures project (Gourley et al. 2007). The discussion here will be based on the Colwell-P test.

Step 2: Determine the target stocking rate

Raising soil fertility will produce more forage and allow more stock to be grazed up until the critical soil test value is achieved and some other environmental factor becomes limiting. The stocking rate— measured as Dry Sheep Equivalents (DSE) per hectare—is strongly related to rainfall and the length of the growing season. Grazing trials in southern Australia have demonstrated that with optimum soil fertility, stocking rates may vary from about 8 DSE/ha for a five-month season to about 20 DSE/ha for a nine-month season.

This information can be used to develop a stocking-rate function relative to Colwell-P soil test value. An example of this is given in **Figure 2** for a long season environment with an upper limit of 20 DSE/ha compared to an unfertilized stocking rate of 6 DSE/ha. This function does not necessarily mean that stocking rates should be increased to 20 DSE/ha as there are other factors to consider such as the availability and cost of additional stock. Stocking rate and its relationship to Colwell P varies with soil type, management system, pasture species and grazing management, so local knowledge is important in adapting this for farm use.

Step 3: Determine the best phosphorus rate

The amount of P to apply will differ if the aim is to either maintain or raise soil P fertility. Maintenance applications will consider exports of P from the paddocks (pastures) in animal products, losses in runoff, and P that accumulates in less available forms that can be adsorbed, precipitated and/or bound into resistant forms—sometimes collectively referred to as "fixed" P. **Table 1** gives a summary of the maintenance P required per DSE for different soil and animal loss factors across different pasture types and rainfall amounts.

These tables were developed as part of a long-term phosphate experiment conducted at The Pastoral and Veterinary Institute, Hamilton, Victoria (Cayley and Saul, 2001).

Phosphorus losses as adsorbed P in eroding soils, or as soluble P in runoff or leaching are of particular environmental concern, but on well managed pastures with good cover the amounts are usually small enough to be ignored for P-fertilizer budgeting purposes.

To achieve the higher stocking rates, the soil P level will need to be raised (**Figure 2**), and this amount is referred to as a capital application. For soils with PBI of 50 to 400, this is around 2.7 to 3.1 kg P/ha, respectively, above the maintenance rate to raise the Colwell P one soil test unit.

In the worked example shown, the objective of increasing the soil test level from 10 to 23 mg/kg would enable the stocking rate to be raised from 6 to 16 DSE/ha. This could be achieved by increasing P application from 5 kg P/ha/yr to 18.8 kg P/ha/yr over five years. After year 5, the capital amount would not need to be added, so the on-going maintenance application would be 13.4 kg P/ha. The combination of the maintenance and capital applications over the first few (5) years can then be economically evaluated in Step 4.

Step 4: Budgeting to check that the options are profitable

While a soil test and P budget will indicate that pasture production and stocking rate can be increased, it does not necessarily generate additional profit. But a cash flow budget can be developed to show the year by year consequences of this fertilizer plan. As part of this program, a spreadsheet calculator has been developed to assist growers to assess the implications of the extra costs of livestock and fertilizer on cash flow. In the first year of many fertilizer plans, there are often cash deficits due to the capital cost of the extra stock. Fertilizer price and stock returns have a large effect on the cumulative cash flow.

A worked example:

Pasture: 40% native perennial grasses, 60% annual grasses and subterranean clover (unimproved, low Animal Loss Factor)
Soil: Podzol, soil derived from granite
Phosphorus Buffering Index: 80
Colwell P: 10 mg P/kg
Average annual rainfall of 800 mm

Objective

To raise Colwell P to 23 mg P/kg and the stocking rate to 16 DSE/ha over 5 years (2.6 mg P/kg/yr, 2.0 DSE/ha/yr)

Capital P calculation

To raise Colwell P by 2 units with this PBI will require 2.7 x 2.6 kg P/ha above maintenance = 7.0 kg P/ha (A)

Maintenance P calculation (Table 1)

Prior to Year 1 = 0.84 kg P/DSE x 6 DSE/ha = 5.0 kg P/ha (B0)
In Year 1 = 0.84 kg P/DSE x 8.0 DSE/ha = 6.7 kg P/ha (B1)
In Year 5 = 0.84 kg P/DSE x 16.0 DSE/ha = 13.4 kg P/ha (B5)

Predicted annual applications to meet capital and maintenance demand (A + B)

Year 1 = 7.0 + 6.7 = 13.7 kg P/ha
Year 5 = 7.0 + 13.4 = 20.4 kg P/ha
On-going maintenance = 13.4 kg P/ha

Table 1. (A) Predicted P requirement per dry sheep equivalent (kg P/DSE) required for different soil loss factors based on soil types; (B) animal loss factors based on grazing intensity and landscape for different pastures with different average annual rainfall.

A. Predicted P requirement per dry sheep equivalent (kg P/DSE) for calculating maintenance P applications.

Soil type	Animal Loss Factor (based on B*)	Poor pasture			Improved pasture		
		Annual rainfall, mm					
		400	600	800	400	600	800
Recent alluvials	Very Low	0.42	0.45	0.48	0.43	0.48	0.53
	Low	0.54	0.58	0.62	0.55	0.62	0.68
	Medium	0.65	0.70	0.75	0.67	0.75	0.83
	High	0.77	0.83	0.89	0.80	0.89	0.98
Podzols, Clay loams	Very Low	0.61	0.65	0.70	0.63	0.70	0.77
	Low	0.72	0.78	0.84	0.75	0.83	0.92
	Medium	0.84	0.91	0.97	0.87	0.97	1.07
	High	0.96	1.03	1.11	0.99	1.11	1.22
Acid Sands, Kraznozems other clays	Very Low	0.80	0.86	0.92	0.82	0.92	1.01
	Low	0.91	0.98	1.05	0.94	1.05	1.16
	Medium	1.10	1.11	1.19	1.06	1.19	1.31
	High	1.15	1.24	1.32	1.18	1.32	1.46

*B. Animal Loss Factors.

Intensive rotational grazing	Flat and rolling country (mostly <10°)	Very low
	Easy hills (mostly <25°)	Low
	Steep hills (one third of the paddock >35°)	Medium
Set stocked or intermittent grazing	Flat and rolling country	Low
	Easy hills	Medium
	Steep hills	High

Generally, paybacks become positive after 3 to 5 years and over time the improved pasture performance will enable higher stocking rates to be carried.

Step 5: Other things to consider before investing

Phosphorus is only one of the essential nutrients required by temperate legume-based pastures, although in many grazing areas it is the primary limitation. If the soil has additional nutrient limitations, such as K, Mo, or S, or if the soil pH is very low, then the responses to applied P can be held back by the other soil deficiencies. Soil tests are important tools for monitoring the nutrient supply for K and S. It is also important to remember to apply micronutrients at recommended intervals if they are required.

In most cases, an increasing P supply will increase the legume content of the pasture, which in turn increases soil N status and lifts productivity. Higher N status may also promote grass dominance. But these changes can be managed through grazing pressure. Rotational grazing and the use of well adapted forages will assist in maintaining desirable species balance and pasture quality.

While the Five Easy Steps approach was developed for clover-based pastures, the principles should apply to P management in any of the world's 3.5 billion ha of soil-pasture system where P has been identified as a limiting nutrient. BC

Acknowledgements

The 'Five Easy Steps' software tool and booklet were developed by CSIRO and Industry and Investment NSW with financial assistance from Pastures Australia, a joint venture of Meat and Livestock Australia (MLA), Grains Research and Development Corporation, Australian Wool Innovation Ltd (AWI), Dairy Australia (DA) and the Rural Industries Research and Development Corporation. Present development of the tool is supported by funding from the Australian Government Department of Agriculture and Water Resources as part of its Rural R&D for Profit programme, MLA, DA and AWI.

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1. Publication Title: Better Crops with Plant Food; **2. Publication Number:** 0006-0089; **3. Filing Date:** 09-19-2017; **4. Issue Frequency:** Quarterly; **5. Number of Issues Published Annually:** 4; **6. Annual Subscription Price:** Free to Subscribers; **7. Complete Mailing Address of Known Office of Publication:** International Plant Nutrition Institute, 3500 Parkway Ln, Suite 550, Peachtree Corners, GA 30092-2844; **Contact Person:** Gavin Sulewski; Telephone: 770-825-8080; **8. Complete Mailing Address of Headquarters of Publisher:** International Plant Nutrition Institute, 3500 Parkway Ln, Suite 550, Peachtree Corners, GA 30092-2844; **9. Full Names and Complete Mailing Addresses of Publisher:** International Plant Nutrition Institute, 3500 Parkway Ln, Suite 550, Peachtree Corners, GA 30092-2844, **Editor:** Gavin Sulewski, International Plant Nutrition Institute, 3500 Parkway Ln, Suite 550, Peachtree Corners, GA 30092-2844, and **Managing Editor:** Gavin Sulewski, International Plant Nutrition Institute, 3500 Parkway Ln, Suite 550, Peachtree Corners, GA 30092-2844; **10. Owner:** International Plant Nutrition Institute; Complete Mailing Address: 3500 Parkway Ln, Suite 550, Peachtree Corners, GA 30092-2844; **11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or Other Securities:** None; **12. Tax Status:** Has Not Changed During Preceding 12 Months; **13. Publication Title:** Better Crops with Plant Food; **14. Issue Date for Circulation Data Below:** August, 2017; **15. Extent and Nature of Circulation: 15a. Total Number of Copies** (Net press run): 11,680 (Average), 10,330 (Nearest filing date); **15b. Legitimate Paid and/or Requested Distribution: (1) Outside County Paid/Requested Mail Subscriptions stated on PS Form 3541:** 1,766 (Average), 1,877 (Nearest filing date); **(2) In-County Paid/Requested Mail Subscriptions stated on PS Form 3541:** 0 (Average), 0 (Nearest filing date); **(3) Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid or Requested Distribution Outside USPS®:** 4,332 (Average), 3,314 (Nearest filing date); **(4) Requested Copies Distributed by Other Mail Classes Through the USPS:** 225 (Average), 150 (Nearest filing date); **15c. Total Paid and/or Requested Circulation** [Sum of 15b (1), (2), (3), and (4)]: 6,323 (Average), 5,341 (Nearest filing date); **15d. Non-requested Distribution: (1) Outside County Nonrequested Copies Stated on PS Form 3541:** 4,615 (Average), 4,537 (Nearest filing date); **(2) In-County Nonrequested Copies Stated on PS Form 3541:** 0 (Average), 0 (Nearest filing date); **(3) Nonrequested Copies Distributed Through the USPS by Other Classes of Mail:** 0 (Average), 0 (Nearest filing date); **(4) Nonrequested Copies Distributed Outside the Mail:** 0 (Average), 0 (Nearest filing date); **15e. Total Nonrequested Distribution** [Sum of 15d (1), (2), (3) and (4)]: 4,615 (Average), 4,537 (Nearest filing date); **15f. Total Distribution** (Sum of 15c and e): 10,938 (Average), 9,878 (Nearest filing date); 15g. Copies not Distributed: 742 (Average), 452 (Nearest filing date); **15h. Total** (Sum of 15f and g): 10,680 (Average), 10,330 (Nearest filing date); **15i. Percent Paid and/or Requested Circulation** (15c divided by 15f times 100): 58% (Average), 54% (Nearest filing date); 17. Publication of Statement of Ownership for a Requester Publication is required and will be printed in the November 2017 issue of this publication.

Signature of Editor: Gavin Sulewski

Date: September 19, 2017

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IPNI Scholar Award Recipients - 2017

The International Plant Nutrition Institute (IPNI) has selected the winners of its annual Scholar Award Program. In 2017, a total of 37 graduate students representing 20 countries, were chosen. Each winner receives the equivalent of US$2,000.

"The selection committee was challenged by a record response by applicants," said Dr. Terry L. Roberts, IPNI President. "This group of IPNI Scholars should be proud of this accomplishment. They have each demonstrated an impressive body of work and are already contributing greatly to the field of plant nutrition," said Roberts.

Graduate students attending a degree-granting institution located in any country within an IPNI regional program are eligible. The award is available to graduate students in science programs relevant to plant nutrition science and the management of crop nutrients including: agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, environmental science, and others.

Regional committees of IPNI scientific staff select the recipients of the IPNI Scholar Award. The awards are presented directly to the students at a preferred location and no specific duties are required of them.

The winners are listed below according to IPNI program and country and university/institution affiliation.

NORTH AFRICA

Siham Baha Eddine
Morocco

Ms. Siham Baha Eddine, **University Ibn Tofail**, Kenitra, Morocco. **Ph.D. Program**: Best Nitrogen, Phosphorus, and Potassium Fertilizer Management to Control Wheat Crown Rot Caused by *Fusarium culmorum*.

SUB-SAHARAN AFRICA

Mrs. Abeba Nigussie Retta, College of Dryland Agriculture and Natural Resources, **Mekelle University**, Mekelle, Ethiopia. **Ph.D. Program**: Managing of Low Carbon and Alkaline Soils in the Cereal-Based Cropping System of the Northern Semiarid Zone of Ethiopia.

Mr. Athuman Mahinda, Tanzanian Study at **Kyoto University**, Graduate School of Agriculture, Japan. **Ph.D. Program**: Influence of In-situ Rain Water Harvesting Techniques and Nutrients Management for Sorghum Production in the Semi-Arid Areas of Tanzania.

Abeba Nigussie Retta
Ethiopia

Athuman Mahinda
Tanzania

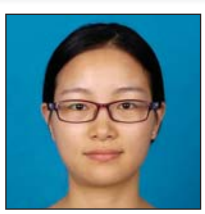
Ruth Atchoglo
Togo

Ms. Ruth Atchoglo, High School of Agronomy, **University of Lomé**, Togo. **M.Sc. Program**: Determination of the Economically Optimum Rates of On-farm Manure and Urea for Maize Grown on Barre Soil Areas.

CHINA

Mr. Chen Zhaoming, Institute of Soil Science, **Chinese Academy of Science**, Nanjing, China. **Ph.D. Program**: Effects of Nitrogen Placement on Wheat Yield and Fate of Urea-^{15}N in the Wheat-soil System in the Middle and Lower Yangtze River Basin.

Chen Zhaoming
China



Fang Xianzhi
China

Liu Chuang
China

Liu Xiaowei
China

Muhammad Shoaib
Rana - China

Ms. Fang Xianzhi, **Zhejiang University**, Hangzhou, Zhejiang, China. **M.Sc. Program**: Nitrate Transporter NRT1.1 Regulates Resistance of Abiotic Stresses in Plant.

Continued on next page

CHINA continued

Mr. Liu Chuang, **Chinese Academy of Sciences**, Moshan, Wuchang, Wuhan, China. **Ph.D. Program**: A Novel Way to Establish Fertilization Recommendations Based on Agronomic Efficiency and a Sustainable Yield Index for Rice Crops.

Mr. Liu Xiaowei, **Chinese Academy of Sciences**, Nanjing, Jiangsu, China. **Ph.D. Program**: Effect of Nitrogen Fertilization Pattern on Rice Yield, Nitrogen Use Efficiency and Fertilizer Nitrogen Fate in the Yangtze River Basin, China.

Mr. Muhammad Shoaib Rana, College of Resource and Environment, **Huazhong Agricultural University**, Wuhan, Hubei, China. **Ph.D. Program**: Effects of Long Term Molybdenum Application on Soil Phosphorus Transformation Characteristics and Bioavailability Based on Microorganism and Plant Interaction.

RUSSIA

Aleksey Guzenko
Russia

Olga Silujanova
Russia

Mr. Aleksey Guzenko, **Volgograd State Agrarian University**, Volgograd, Russia. **M.Sc. Program**: The Experience of Liquid Complex Fertilizer Use to Sunflower in Rodina Agrienterprise in Kikvidze District of Volgograd Oblast.

Ms. Olga Silujanova, **Vologda State Dairy Academy**, Vologda, Russia. **Ph.D. Program**: Agroecological Efficiency of Biologically Modified Organic-Mineral Fertilizers in the Cultivation of Crops on Sod-Podzolic Light Loamy Soils.

MIDDLE EAST

Ms. Raheela Rehman, **Sabanci University**, Istanbul, Turkey. **Ph.D. Program**: Uptake, Transport and Seed Deposition of Zinc and Iodine in Wheat and Maize.

Raheela Rehman
Turkey

NORTH AMERICA

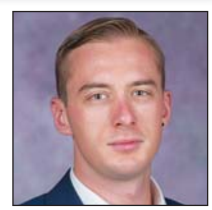
Joshua Nasielski
Canada

Leonardo Bastos
United States

Joel Crowther
United States

Josh Henry
United States

Natalie Ricks
United States



Joseph (Jay) Weeks
United States

Mr. Joshua Nasielski, **University of Guelph**, Guelph, Ontario, Canada. **Ph.D. Program**: The Nitrogen Economy of Agroecosystems: Soil Moisture as Regulator of Maize Nitrogen Demand.

Mr. Leonardo Bastos, **University of Nebraska-Lincoln**, Lincoln, Nebraska, United States. **Ph.D. Program**: Integrating Fertilizer Field Strategies, Crop Canopy Sensors and Crop Models for Nitrogen Management in Irrigated Corn Systems.

Mr. Joel Crowther, **University of Nebraska-Lincoln**, Lincoln, Nebraska, United States. **M.Sc. Program**: Integrating Management Zones and Canopy Sensing to Improve Nitrogen Recommendation Algorithms.

Mr. Josh Henry, **North Carolina State University**, Raleigh, North Carolina, United States. **Ph.D. Program**: Characterization of Tobacco Abiotic Disorders Using Unmanned Aerial Vehicle Analysis.

Continued on next page

NORTH AMERICA continued

Ms. Natalie Ricks, **University of Minnesota**, Saint Paul, Minnesota, United States. **M.Sc. Program**: Improving Nitrogen Management and Water Quality with Cover Crops and Living Mulches for Corn Cropping Systems on Irrigated Coarse-Textured Soils in Minnesota.

Mr. Joseph (Jay) Weeks, **Kansas State University**, Manhattan, Kansas, United States. **Ph.D. Program**: Elements of Surprise: Investigations into the Fate and Transport of Historically Mismanaged Lead and Phosphorus to Better Protect Humans and the Environment.

AUSTRALIA & NEW ZEALAND


Chelsea Stroppiana
Australia


Amy Whitley
New Zealand

Ms. Chelsea Stroppiana, **The University of Queensland** - School of Agriculture and Food Science / Queensland Alliance for Agriculture and Food Innovation, Queensland, Australia. **Ph.D. Program**: Improving Nitrogen Use Efficiency in High Risk Environments.

Ms. Amy Whitley, **Lincoln University**, Canterbury, New Zealand. **Ph.D. Program**: Soil pH and Aluminum Toxicity in New Zealand High and Hill Country Soils.

LATIN AMERICA - SOUTHERN CONE

Ms. Stefania Appelhans, **University of Buenos Aires**, Buenos Aires, Argentina. **Ph.D. Program**: Contribution of Organic Fractions to the Diagnosis of Phosphorus Fertility in Corn and Soybean.

Prof. Oswaldo Ernst, College of Agronomy-**Universidad de la Republica Oriental del Uruguay,** Paysandú, Uruguay. **Ph.D. Program**: Estimation of the Wheat Yield Gap in Uruguay: Loss of Soil Quality as a Determining Factor.


Stefania Appelhans
Argentina


Oswaldo Ernst
Uruguay

BRAZIL


Gerson Laerson
Drescher - Brazil


Danilo Silva Almeida
Brazil


Nicolás Ignacio
Stahringer - Brazil


Hugo González-Villalba
Brazil

Mr. Gerson Laerson Drescher, **Federal University of Santa Maria**, Rio Grande do Sul, Brazil. **Ph.D. Program**: Nitrogen Distribution in the Soil Profile and Soil Sampling Depth to Calibrate the Direct Steam Distillation Method for Flooded Rice.

Mr. Danilo Silva Almeida, **São Paulo State University**, Botucatu, São Paulo, Brazil. **Ph.D. Program**: Soil Phosphorus Availability in Soybean-Ruzigrass Crop Rotation.

Mr. Nicolás Ignacio Stahringer, **Federal University of Viçosa**, Viçosa, Minas Gerais, Brazil. **Ph.D. Program**: Parameterization of Productivity and Nutritional Balance Models for *Pinus* and *Eucalyptus* in Corrientes – Argentina.

Mr. Hugo González-Villalba, **University of São Paulo**, Piracicaba, São Paulo, Brazil. **Ph.D. Program**: Agronomic Efficiency of Starter Fertilization in Maize Using a Mixture of Commercial Urea and Polymer Coating of Sulfur-Coated Urea.

Funding for the scholar award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers.

More information is available from IPNI staff, individual universities, or from the IPNI website: www.ipni.net/awards. Short biographies for each Scholar are available from http://www.ipni.net/article/IPNI-3474. BC

SOUTH ASIA

A.K.M. Mahbub Ur Rahman - Bangladesh

Mahasweta Chakraborty - India

Jemila Chellappa India

Suresh Kumar Kakraliya - India

Adenipekun Gabriel Shitu - India

Nandkishore Sudhakar Thombare - India

Veena Kumari Tudu India

Bandhu Raj Baral Nepal

Aqsa Nazeer Pakistan

R.A. Asanka Ratnnayaka - Sri Lanka

Mr. A.K.M. Mahbub Ur Rahman, **Bangladesh Agricultural University**, Mymensingh. **Ph.D. Program**: Agronomic Options to Iron, Zinc and Selenium Biofortification of Lentil.

Ms. Mahasweta Chakraborty, **Bidhan Chandra Krishi Viswavidyalaya**, West Bengal, India. **Ph.D. Program**: Zinc Profiling and its Biofortification of Crops for Improving Bioavailability.

Ms. Jemila Chellappa, **Tamil Nadu Agricultural University**, Tamil Nadu, India. **Ph.D. Program**: Integrated Zinc Nutrient Management on Growth, Yield, and Grain Zinc Enrichment of Pearlmillet in Calcareous Soils.

Mr. Suresh Kumar Kakraliya, **CCS Haryana Agricultural University**, Hisar, Haryana, India. **Ph.D. Program**: Participatory Assessment of Portfolios of Climate Smart Agricultural Practices for Adapting Rice-Wheat Cropping System to Climate Variability in Climate Smart Villages of Haryana.

Mr. Adenipekun Gabriel Shitu, **ICAR - Indian Agricultural Research Institute**, New Delhi, India. **Ph.D. Program**: Assessment of Precision Conservation Agricultural Practices and their Perceived Impact on Climate Smart Agriculture in Indo-Gangetic Plain.

Mr. Nandkishore Sudhakar Thombare, **Birla Institute of Technology**, Mesra, Ranchi, Jharkhand, India. **Ph.D. Program**: Synthesis and Evaluation of Cross-Linked Guar Gum Hydrogels for Environmental and Agricultural Applications.

Ms. Veena Kumari Tudu, **Birsa Agricultural University**, Kanke, Ranchi, Jharkhand, India. **Ph.D. Program**: Genetics of Drought Tolerance in Maize under Different Potassium Levels.

Mr. Bandhu Raj Baral, **Agriculture and Forestry University**, Rampur, Chitwan, Nepal. **Ph.D. Program**: Enhancing Nitrogen Use Efficiency in Rice under Rain-fed Conditions in Nepal.

Ms. Aqsa Nazeer, Pakistan Department of Agronomy, **Bahauddin Zakariya University Multan**, Multan, Pakistan. **M.Sc. Program**: Role of Potassium Nutrition in Oxidative Stress-induced Disruption of Source-Sink Carbon Metabolism During Boll Shedding of Cotton Under Heat Stress.

Mr. R.A. Asanka Rathnayayka, Postgraduate Institute of Agriculture, **University of Peradeniya Mirigama**, Sri Lanka. **M.Sc. Program**: Site-Specific Nutrient Management for Paddy Soils on the Basis of Potential Management Zones Delineated through Proximal Soil Sensing.

SOUTHEAST ASIA

Hayat Ullah Thailand

Mr. Hayat Ullah, Food Agriculture and Bioresources, **Asian Institute of Technology**, Bangkok, Thailand. **Ph.D. Program**: Evaluation of Different Nutrient Management Strategies for Rice Cultivation in the Context of Decreasing Water.

Fertilizing High Yielding Alfalfa in California and Arizona

By Nicholas Clark, Steve Orloff, and Mike Ottman

Some of the highest alfalfa yields in the world are grown in California and Arizona, with yields as high as 24 t hay/A reported. **Three distinct alfalfa-growing environments provide** examples of the nutrient management required to achieve high yields.

California (CA) and Arizona (AZ) are home to some of the world's highest yielding alfalfa fields. Average annual hay yields grown on the region's 1.1 to 1.2 million acres range from 5.5 to 9.0 tons/A. This represents 6% of the U.S. acreage and 10% of the production. Proper fertility management is key to producing high yield in these two states. Three particular alfalfa-producing regions will be discussed in this article: CA Intermountain, CA Central Valley, and the CA and AZ deserts.

While the environmental conditions and management practices differ greatly across these regions, there is common ground regarding methods for detecting and correcting nutrient deficiencies. The basis of this commonality is the alfalfa plant itself. Well-functioning alfalfa plants need the same proportion of nutrients to perform basic life functions and produce biomass no matter where grown.

The first thing to consider in nutrient management planning is the yield potential of each field. That number can be used to calculate potential nutrient removal and help guide fertilizer rate recommendations (**Tables 1** and **2**). Soil, plant tissue, and water analyses are the best way to determine the need for corrective action to resolve an alfalfa nutrient problem (**Tables 3** and **4**). Establishing benchmark soil and tissue testing areas (specific spots in the field where samples are collected year after year) helps to reveal trends in nutrient levels—either building or mining.

The macronutrients most limiting to CA and AZ alfalfa production are P, K, and S. Molybdenum and B deficiency may also occur in Intermountain CA.

Intermountain CA

Alfalfa is the number one irrigated crop in terms of acreage in the Intermountain area of northern CA. Production occurs in high-elevation valleys (2,500 ft. to 5,000 ft.) scattered throughout the region. Due to the latitude and the elevation, these valleys have a shorter growing season and cooler temperatures than the other production areas of California. Annual production is typically 4.5 to 8 tons/A (5 to 6.5 tons/A is most common) from 3 to 4 cuttings/yr. Alfalfa fertilization is more complicated in Intermountain area than in most other alfalfa production areas of CA for several reasons:

1. Because alfalfa is the dominant crop, most fields do not benefit from carryover nutrients from a preceding higher input crop like tomatoes, cotton, or melons.
2. A first cutting yield of 2 to 3 tons/A is commonplace and results in a relatively high nutrient demand.
3. Soil temperatures are low in spring, which affects nutrient availability at a critical growth period.
4. Many soils are inherently lower in fertility than in other regions.

Phosphorus is the most commonly deficient nutrient and

Table 1. Alfalfa nutrient removal during hay harvest.

	Annual alfalfa yield, tons/A				
	6	8	10	12	15
Nutrient	Nutrient removal, lbs/A				
Nitrogen	360	480	600	720	900
Phosphorus (P_2O_5)	31 (71)	42 (95)	52 (119)	62 (143)	78 (179)
Potassium (K_2O)	240 (288)	320 (384)	400 (480)	480 (576)	600 (720)
Calcium	192	256	320	384	480
Magnesium	40	53	66	79	99
Sulfur	24	32	40	48	60
Iron	2.3	3	3.8	4.6	5.7
Manganese	1.5	2	2.5	3	3.8
Chloride	1.5	2	2.5	3	3.8
Boron	0.4	0.5	0.6	0.7	0.9
Zinc	0.3	0.4	0.5	0.6	0.75
Copper	0.12	0.16	0.2	0.24	0.3
Molybdenum	0.024	0.032	0.04	0.048	0.06

Adapted from Summers and Putnam (2008).

Table 2. Alfalfa fertilization recommendations.

		Soil or plant tissue test result		
	Yield,	Deficient	Marginal	Adequate
Nutrient	tons/A	Fertilizer application rate, lbs/A		
Phosphorus (P_2O_5)	4	60-90	30-45	0-20
	8	120-180	60-90	0-45
	12	180-270	90-130	0-60
Potassium (K_2O)	4	100-200	50-100	0-50
	8	300-400	150-200	0-100
	12	400-600	200-300	0-150

Adapted from Summers and Putnam (2008); Orloff (1997).

Table 3. Reliability of alfalfa fertility testing method.

Nutrient	Soil Testing	Tissue Testing
Phosphorus	Good	Excellent
Potassium	Good	Excellent
Sulfur	Very poor	Excellent
Boron	Poor	Excellent
Molybdenum	Not recommended	Excellent

Adapted from Summers and Putnam (2008).

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; S = sulfur; B = boron; Cl = chloride; Cu = copper; Fe = iron; Mo = molybdenum; Mn = manganese; Zn = zinc.

Table 4. Interpretation of plant tissue and soil test results for alfalfa production.

Nutrient	Plant Part	Unit	Deficient	Marginal	Adequate	High
			- - - - - - - - - - Plant tissue concentration	- - - - - - - - -		
Phosphorus (PO_4-P)	Middle third, stems	ppm	300-500	500-800	800-1500	> 1500
Potassium	Middle third, stems	%	0.40-0.65	0.65-0.80	0.80-1.50	> 1.50
Sulfur (SO_4-S)	Middle third, stems	ppm	0-400	400-800	800-1000	> 1000
Boron	Top third	ppm	< 15	15-20	20-40	> 200
Molybdenum	Top third	ppm	< 0.3	0.3-1.0	1.0-5.0	5.0-10.0
			- - - - - - - - - - - - Soil concentration	- - - - - - - - - - - -		
Nutrient	Extractant	Unit	Deficient	Marginal	Adequate	High
Phosphorus	Bicarbonate	ppm	< 5	5-10	10-20	> 20
Potassium	Ammonium acetate	ppm	< 40	40-80	80-125	> 125
	Sulfuric acid	ppm	< 300	300-500	500-800	> 800
Boron	Saturated paste	ppm	< 0.1	0.1-0.2	0.2-0.4	> 0.4

Adapted from Summers and Putnam (2008).

Alfalfa-producing regions of California and Arizona, USA.

is critical for high yield. Application of P fertilizer at least 60 to 90 days before the first cut produces maximum benefit. The greatest P response typically occurs on the first cut, because the yield is usually higher for this cutting, and nutrient availability is lower due to cool soil temperatures. Therefore, a fall or winter P application is more effective than mid-season applications.

Sulfur is the next most common nutrient deficiency. The source of S to use depends on soil S availability and the soil pH. If the field is very S deficient, a small particle size elemental S source is recommended for rapid oxidation to the sulfate form available for plant uptake. Gypsum is an alternative for low pH soil, because the S in gypsum is already in the sulfate form, and gypsum does not alter soil pH, whereas elemental S applications reduce pH. For moderately S deficient conditions, and pH neutral or alkaline fields, elemental S is the most cost-effective source. Two hundred to 300 lb S/A is an effective rate and should last for multiple years.

Potassium deficiency occurs in portions of the intermountain area. Deficiency symptoms are distinctive (spotting and yellowing along leaf margins).

Boron and Mo deficiencies are known to occur in Intermountain CA, particularly on low pH soils. There is a relatively narrow margin between deficiency and toxicity of some micronutrients (especially B), so it is important to apply the proper rate. A multiple-year supply can be applied. Often these nutrients are applied in liquid form and sprayed on during the dormant season.

Central Valley CA

Approximately 70% of CA alfalfa is produced in the Central Valley (CV), which is comprised of the Sacramento Valley (SV) in the north and San Joaquin Valley (SJV) in the south. Production spans from the San Joaquin/Sacramento Delta at sea level to the northern and southern valley boundaries at 500 ft. elevation. Soils range from high organic matter mucks near the Delta, to highly mineral alluviums from the enclosing mountain ranges and an ancient sea bed. A long growing season makes 7 to 9 cuts possible each year. Annual yields average 8 tons/A with some growers reporting up to 15 tons/A. Most varieties grown in this region have an Fall dormancy rating of 4 to 9 with more dormant varieties grown in the SV.

The most common nutrient deficiencies are P, K, and S. For regularly manured fields that are rotated with dairy forages, P deficiency is less common as P has a tendency to accumulate when crop N needs are met with dairy manure. However when soil tests are low, P fertilizer should be applied. When rotating into alfalfa, banded P fertilizer applications at planting increase P fertilizer efficiency. In established alfalfa fields, broadcast topdress applications of granular P fertilizer are usually made in late winter before the first cutting.

Although much less common than a P deficiency, K deficiency can also occur. It is most common on the sandier soils in the eastern SV and northern SJV. For most of the CV, K fertilizer is not needed. Fields that are regularly amended with dairy manure are unlikely to experience K deficiency and may have excess K, which can negatively impact feed quality of alfalfa.

Sulfur deficiency causes stunting and general yellowing, but may be difficult to identify by visual symptoms. Sulfur deficiency is more common in fields that receive irrigation water from snowmelt and where salinity tends to be low. Tissue testing is the only reliable way to determine an S deficiency. Further, if a S deficiency is suspected, tissue testing should occur in the late winter after the first cut when cooler soil temperatures tend to inhibit S oxidation to sulfate. If a S deficiency exists, this will be the time of year it is most likely apparent.

CA and AZ Deserts

The deserts of CA and AZ are characterized by a hot, dry climate and by soils that are alkaline (pH>7) and calcareous (containing free calcium carbonate, or lime). Phosphorus is the nutrient most often deficient in this region due to the high P-fixing capacity of these soils where soluble P is readily converted to insoluble mineral compounds. Phosphorus deficiency is most likely when the crop is growing during the cooler times of the year. Deficiencies of other nutrients such as K are also possible in this region, but are rare.

Splitting a P fertilizer application has not been shown to be an effective practice (**Figure 1**). Phosphorus fertilizer application timing is best when the crop is coming out of dormancy in the late winter or early spring, as P is more likely to be needed in the spring when temperatures are relatively cool. If an application is split, the amount of fertilizer applied at each application needs to be high enough to bring the soil test level P into the sufficient range.

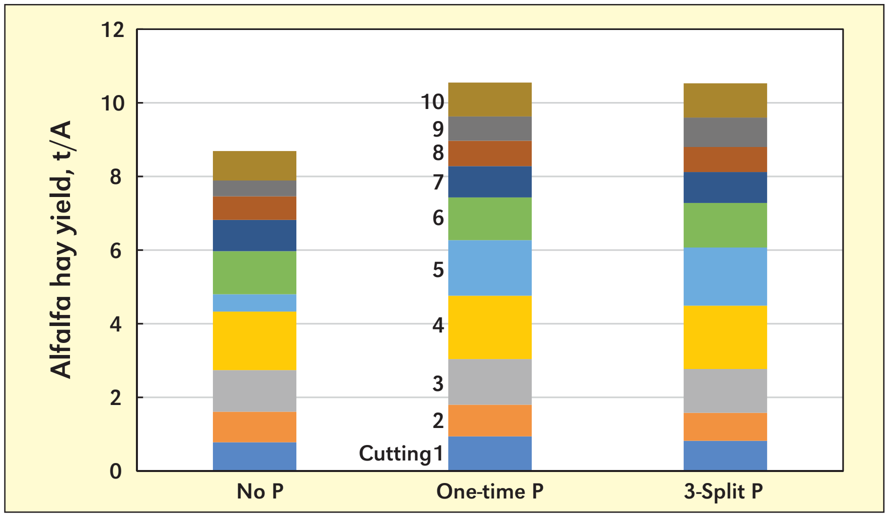


Figure 1. Alfalfa hay yield as affected by no P, a single application (117 lb P_2O_5/A), or three applications (39 lb P_2O_5/A) of MAP (monoammonium phosphate) over ten cuttings. Buckeye, AZ, 2015. Initial Olsen soil P concentration of 4 ppm (Ottman, unpublished).

The source of P fertilizer may affect alfalfa yield response in the deserts of CA and AZ. Phosphorus may be more available with acid-forming fertilizers such as phosphoric acid because less of the P may be rapidly fixed. Also, P held in organic form such as in manure is not subject to fixation by soil minerals such as what occurs with inorganic sources of P fertilizer. Granular MAP was found to be slightly more effective than water-run liquid ammonium polyphosphate (APP) for alfalfa nutrition (Ottman et al., 2006). MAP tended to move deeper into the soil, although the convenience of applying APP with the irrigation water should also be considered.

T. Roberts/IPNI

Potassium deficiency in alfalfa.

Potassium is usually at high concentrations in the desert soils of CA and AZ. However, K deficiency in alfalfa can occur on sandy soils and on soils with a history of crops that remove a large amount of K such as alfalfa and cotton. A deficiency is readily corrected with the application of granular K fertilizers.

TSI Image

Sulfur deficiency (right) vs. normal alfalfa plant (left).

N. Miles/IPNI Image

Boron deficiency in alfalfa.

Summary

The differences in soil fertility and climate that range from the northern border of CA to the desert valleys of AZ require different fertilization practices tailored to the needs of each region. However, plant nutrient requirements based on yield potential and testing programs to determine deficiencies remain constant. Knowing and using each field's yield potential as a guide for determining crop nutrient requirements is a universal tool. Soil and plant tissue testing for P and K and plant tissue testing for S, Mo, and B are the best ways to discover a nutrient deficiency and create a prescription for correction. These are the tried and true methods of maintaining high yielding alfalfa fields in this region. BC

Mr. Clark (e-mail: neclark@ucanr.edu) and Mr. Orloff are Farm Advisors, Univ. Calif. Coop. Ext. Dr. Ottman is Ext. Agronomist, Univ. Arizona (e-mail: mottman@ag,arizona.edu).

References

Orloff, S. 1997. Intermountain Alfalfa Management. UCANR Publ 3366.
Ottman, M.J. et al. 2006. Agron. J. 98:899-906.
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Tifton 85 Bermudagrass Response to Fertilization on Two Coastal Plain Soils

By William Anderson and Mike Stewart

Among the forage bermudagrasses, Tifton-85 is recognized for several positive attributes that led to it being the cultivar of choice in many regions of the world.

Given its greater yield potential and improved quality characteristics compared to other bermudagrasses, a more tailored approach to nutrient management would benefit Tifton-85 producers ...which was the goal of the work reported here.

Bermudagrass [*Cynodon dactylon* (L.) Pers.] is grown for pasture or hay on approximately 15 million acres in the southern U.S., and is the leading warm season perennial forage species. Forage bermudagrass improvement began with the USDA-ARS in Tifton, GA with Dr. Glenn Burton in 1937. 'Coastal' was released in 1943 as the first of many improved forage bermudagrass cultivars. Nearly 50 years later 'Tifton 85' (PI 672166) was released, which is darker green, taller, and was found to produce up to 25% more dry matter and was 11% more digestible than Coastal. Though Coastal is a true bermudagrass (*Cynodon dactylon*), Tifton 85 is a cross between Tifton 68 stargrass (*C. nlemfuensis* Vanderyst) and a *C. dactylon* introduction, PI 290884. For this reason Tifton 85 has very distinct phenotypic (observable) traits including few rhizomes and very aggressive stolons.

Hybrid forage bermudagrasses, including Tifton 85, are generally grouped together for fertilizer and lime recommendations, based on soil test values. However, bermudagrass cultivars may not have the same nutrient needs. For example, Brink et al. (2004) found that Tifton 85 bermudagrass contained about 11% more P than Coastal in a four-year study on a fine sandy loam where high rates of N, P, and K were applied as broiler litter. Tifton 85 is different from other hybrids in growth habit, yielding ability, nutritive value, concentration of some nutrients, and seasonal growth, but there is very limited information on the fertilizer requirements of this grass. This article examines research that was designed to 1) determine the yield response of Tifton-85 to N at low, medium, and high levels of PK input; 2) measure nutrient uptake in forage for each harvest; 3) determine the effects of the fertilizer treatments on forage quality; and 4) determine the most economical N rate to maximize the rate of return.

Study Description

Established sods were utilized to conduct two experiments with Tifton 85 bermudagrass from 2004 to 2007 on the University of Georgia Coastal Plain Experiment Station at Tifton, GA. One Tifton 85 sod was established on a Carnegie sandy loam soil ten years prior to the beginning of this trial, and had been left idle without any fertilization. This sod was maintained by multiple mowings each year. The second location was on a Fuquay loamy sand soil, and was also established ten years prior to the test, but had been grazed and well managed with yearly addition of 300 lb N/A and 120 lb K_2O/A for five years before the initiation of the study. Soil test levels (0 to 10-in. depth, Mehlich I) at the Carnegie site were 8 ppm P (low) and 37 ppm K (medium), and at the Fuquay site levels were 28 ppm for both P (medium) and K (low). Levels of these nutrients below this depth declined significantly in both soils.

Abbreviations and notes: N = Nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; ppm = parts per million.

Harvesting Tifton 85 research plots. The bermudagrass cultivar has become the choice forage among many ranchers and hay producers in the southern U.S. as well as other countries such as Brazil, Mexico, and Venezuela.

Treatments for the experiments were annual N rates of 200, 300, 400, 500, 600, and 700 lb N/A as the main plots and low, medium, and high rates of P and K as subplots. Low, medium, and high rates of P and K represented approximately 50, 100, and 150%, respectively, of the two elements taken up in the forage for the 18 treatments (six main plots × three subplots). As P and K were extracted during harvests and measured for each growing season and over years, the amount of P and K applied for a particular treatment was adjusted to meet the goals of the study. While specific rates for each treatment are not presented here, note that across both soils rates ranged from approximately 40 to 145 lb P_2O_5/A, and 205 to 655 lb K_2O/A.

The sources of N, P, and K were ammonium nitrate, triple superphosphate, and potassium chloride, respectively. Gypsum ($CaSO_4$) was included to supply 13 lb S/A per application. Dolomitic limestone, applied at the ratio of 4:1, limestone:N rate, regulated the soil pH and provided Mg for the grass. Ingredients for each subplot treatment were mixed and applied four times each year except the last year when only three applications were made. This required 15 total applications during the study. Each year the first application was made the last week in March and succeeding applications following the first, second, and third harvests. The last harvest each year measured residual effects from previous applications of treatments.

Forage was harvested six times during the growing season (May to October) in 2004, 2005, and 2006; however, in 2007 there were only four harvests from July to October due to a May-June drought.

Yield Response to Fertilizer Treatments

Since year x N and year x PK interactions were not significant, results are presented as an average over four years. Yield significantly increased from the lowest N application rate to 400 lb N/A then leveled off with higher rates at the Fuquay location, but continued to increase at the Carnegie soil location to the 500 lb N/A treatment (**Figure 1**). On the Carnegie soil, PK replacement had no effect at lower N rates, but at 500 lb N/A and above, greater replacement of P and K resulted in higher yields. On the Fuquay soil, higher fertilizer replacement of P and K resulted in slightly higher yields, but the effect was only significant at N rates of 400 and 500 lb N/A.

Overall, the Carnegie soil location responded to N fertilization rates to a greater extent than the Fuquay location. This is likely because the Carnegie location had been depleted by lack of maintenance prior to the trial, while the Fuquay soil location had been fertilized and well maintained. But the Fuquay soil is sandier than the Carnegie soil, so it is expected that the nutrient holding capacity of the Fuquay soil would be slightly lower. The late June to early July harvests (second in the first three years, and first in 2007) tended to have the highest yields, while the midsummer (late July to early August) and final harvests tended to have lower yields (data not shown), though there was some variation across years due in part to differences in rainfall. The majority of the yield responses to N rate occurred during the first and last harvest at each location (data not shown). Fertilizer timing strategies for this grass may require further refinement.

Nitrogen Recovery and Nutrient Uptake

Figure 2 shows an approximation of the balance between N removed in harvested forage and N fertilizer applied (i.e., removal to use or partial N balance) across years and sites. This N balance tended to decline at higher application rates, except in 2007 (drought year) at the Carnegie site where it was low (52% average) and flat across N rates. In the first two years the N balance was close to or exceeded 100% of the amount applied at lower application rates, particularly at the Fuquay site. Even at the highest fertilization rate (700 lb N/A), greater than 70% of the applied N was recovered in 2004 and 2005. As the study progressed, the average N balance declined presumably as native supplies of N were depleted, although rainfall also appears to have been a factor.

A common general range of yearly N fertilizer application for Tifton 85 bermudagrass is 300 to 400 lb/A. The 4-year average partial N balance for the 300 and 400 lb N rates at the Carnegie site was 84 and 77%, and at the Fuquay site it was 109 and 102%, respectively. If the 2007 drought year is removed, then the 3-year average N balance from the Carnegie site increases to 95 and 87%, and for the Fuquay site 119 and 110%. These data illustrate the exceptional ability of forage bermudagrass to intercept and utilize N fertilizer.

The P and K treatments had a small effect on the N balance at the Fuquay site; across years and N rates, the high PK rate increased N recovery by about 6% over the low PK rate (data not shown). It should be noted though that there was no zero

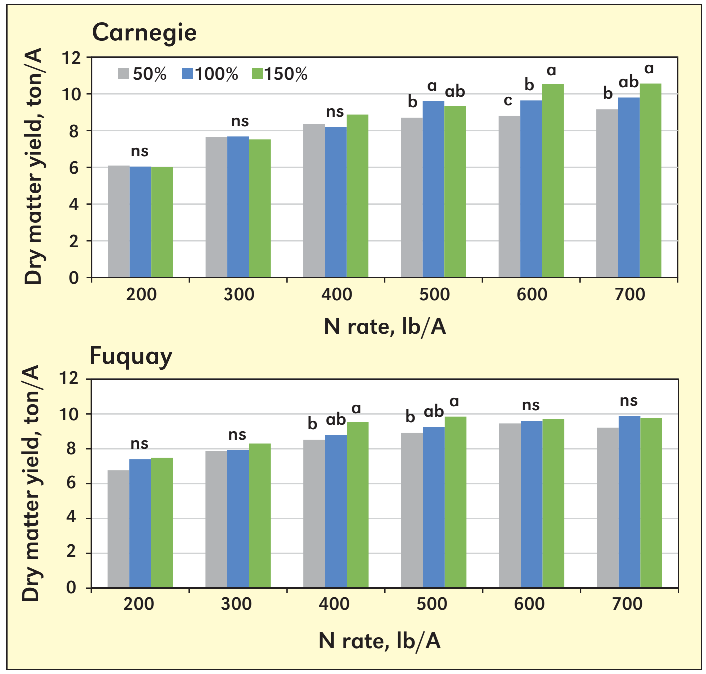

Figure 1. Average (2004 to 2007) dry matter yield response of Tifton 85 bermudagrass at 50%, 100%, and 150% replacement of P and K within six N fertilization rates on Carnegie soil (top) and Fuquay soil (bottom) in Tifton, GA. Within N fertilizer treatments, means with the same letter are not different. The PK treatment was not significant within N treatments marked with 'ns.'

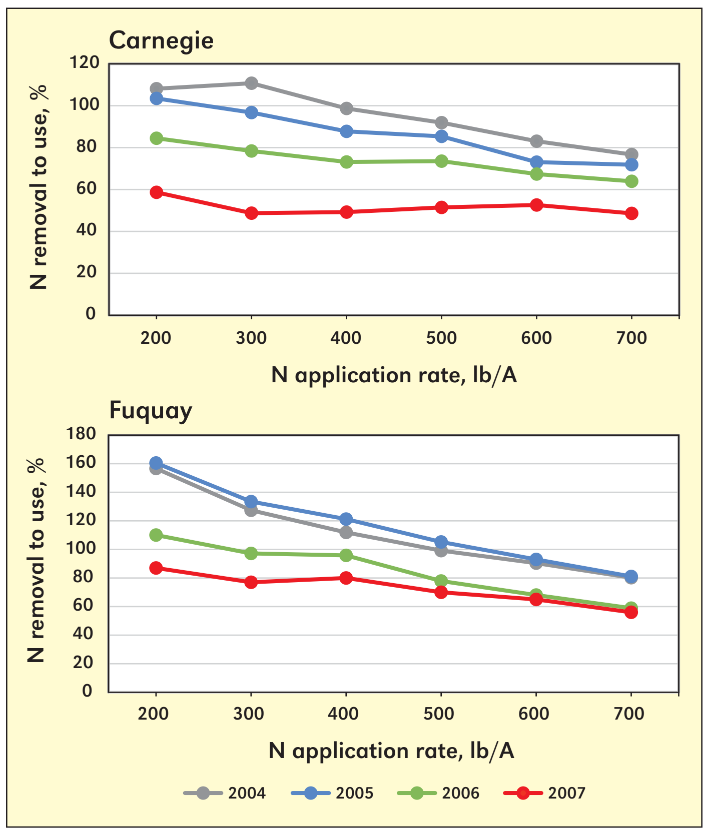

Figure 2. Removal to use for applied N in harvested forage of Tifton 85 bermudagrass grown between 2004 and 2007 at six N application rates near Tifton, GA at (top) Carnegie and (bottom) Fuquay soil locations.

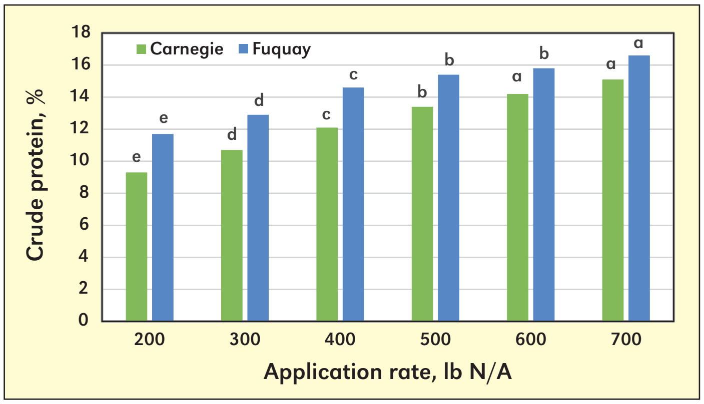

Figure 3. Crude protein content of Tifton 85 bermudagrass forage grown between 2004 and 2007 at six N application rates at two locations (Carnegie soil and Fuquay soil) near Tifton, GA. Within locations, means with the same letter are not different.

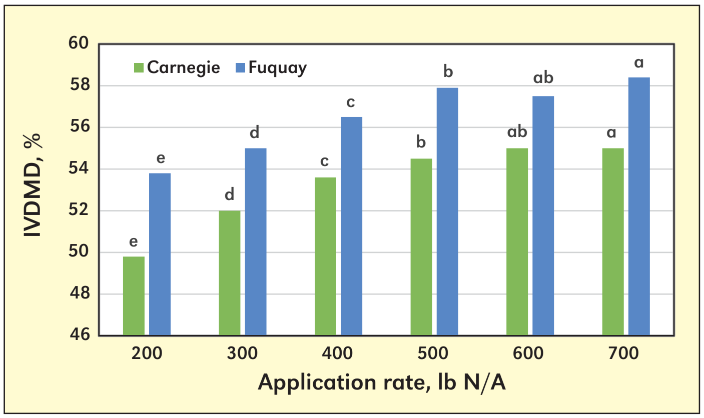

Figure 4. Percent *in-vitro* dry matter digestibility (IVDMD) of Tifton 85 bermudagrass forage grown between 2004 and 2007 at six N application rates at two locations (Carnegie soil and Fuquay soil) near Tifton, GA. Within locations, means with the same letter are not different.

PK treatment, so a measure of the full impact of these nutrients on N recovery was not possible.

While more detailed nutrient uptake information is not presented here, it is available in the source article (Anderson et al., 2016), and results suggest that the N-P_2O_5-K_2O fertilizer ratio for Tifton 85 bermudagrass should be about 3:1:4 at the lowest N rate (200 lb N/A), 4:1:5 at the moderate N rates (300 and 400 lb N/A), and 5:1:5 at the high N rates (500 to 700 lb N/A).

Forage Quality

Crude protein (CP) content of the forage tended to increase with N application rate (**Figure 3**). Application rate of P and K did not affect CP content, although P and K contents of the forage were both correlated with N content. Across all years and harvests, CP content increased at both sites as N application progressed from 200 to 700 lb N/A. Also, % in-vitro dry matter digestibility (IVDMD) increased in a similar pattern over the range of N applications: from 50% to 56% at the Carnegie location, and from 54% to 58% at the Fuquay location (**Figure 4**). Nitrogen content and % IVDMD were highly correlated (r = 0.684 at Carnegie, and r = 0.553 at Fuquay); however, the effect of N fertilizer rate on IVDMD was not as consistent as with CP content. Percent IVDMD was negatively correlated with neutral detergent fiber (NDF) content, but was not correlated with acid detergent fiber (ADF) content. Even in the absence of yield differences, the higher CP content and higher digestibility enhances the quality of Tifton 85 hay at higher N application rates. Improvement in these quality parameters is especially important for the performance of growing calves and lactating cows.

Economic Analysis

A detailed economic analysis was conducted to determine the optimum N rate, and is reported in detail in the original paper (Anderson et al., 2016); however, in the interest of space only a brief summary is provided here. It was assumed that profit-maximizing producers will increase the amount of N fertilizer applied up until the application of one more unit of N will cost more than the value of the additional hay produced. Rates used for P and K in the analysis were 100% of removal. Profits on the Carnegie soil were maximized at 300 lb N/A with net returns (NR) of US$360/A. For the Fuquay soil, profits were maximized at 200 lb N/A for NR of $407/A. Adding an additional 100 lb N/A resulted in losing $9 and $16/A, respectively.

Changing hay or fertilizer prices to reflect historic price variations resulted in significant changes to the optimum levels of N fertilization. With an optimistic scenario (high hay price and low fertilizer prices) optimum levels of N on the Carnegie soil increased to 600 lb N/A with NR of $732/A, and on the Fuquay soil 500 lb N/A with NR of $740/A. A pessimistic scenario (low hay and high fertilizer prices) reduces optimum levels of N to 200 lb N/A for both soil types with NR of $11 and $47/A for the Carnegie and Fuquay soils, respectively.

These results are consistent with generally recommended rates of 300 to 400 lb N/A. However, the variation in NR due to price changes highlights the importance of producers accounting for input and hay price fluctuations.

Summary

This four-year study was conducted to determine the response of rain-fed Tifton 85 bermudagrass to six rates of N, and three rates of PK fertilization at two Georgia (U.S.) locations. Application of 200 to 400 lb N/A along with P and K applied at replacement (removal) levels resulted in maximum economic return. Nutrient uptake results indicate that N-P_2O_5-K_2O ratio varies with N fertilization rate, and that forage bermudagrass is very efficient at recovering applied N fertilizer, with average recovery (partial N balance) reaching over 100% at the 300 lb N rate. Also, crude protein and IVDMD of forage responded positively to increasing rates of N fertilization. BC

Acknowledgment

This article is a summary of work originally reported in 2016 by Anderson, W., M.B. Parker, J.E. Knoll, and R.C. Lacy by Agron. J. 108:1542-1551.

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Critical Phosphorus Concentration in Cool Season Forage Grasses

By Gilles Bélanger and Noura Ziadi

Improved methods for predicting fertilizer P requirements of field crops, including forage grasses, are required to minimize the risk of surface and groundwater contamination from excessive fertilization, while still applying sufficient P to optimize crop yield.

Because soil P tests are not always reliable predictors of fertilizer P requirements, the crop P status could be an alternative or a complement as an indicator of soil P availability.

Plant-based methods for quantifying the crop nutrition status, including P, depend on the definition of a critical concentration, that is, the minimum concentration of a given nutrient required to achieve maximum crop growth and yield. Crop P concentration decreases during growth as does N concentration, and it also decreases with decreasing N concentration associated with N deficiency (**Figure 1**). This strong dependence between crop P and N concentrations was confirmed for several field crops, including corn (Ziadi et al., 2007), wheat (Bélanger et al., 2015a), canola (Bélanger et al., 2015b), and forage grasses (Bélanger and Ziadi, 2008), and led to the development of models of critical P concentration (P_c) defined as a function of shoot N concentration.

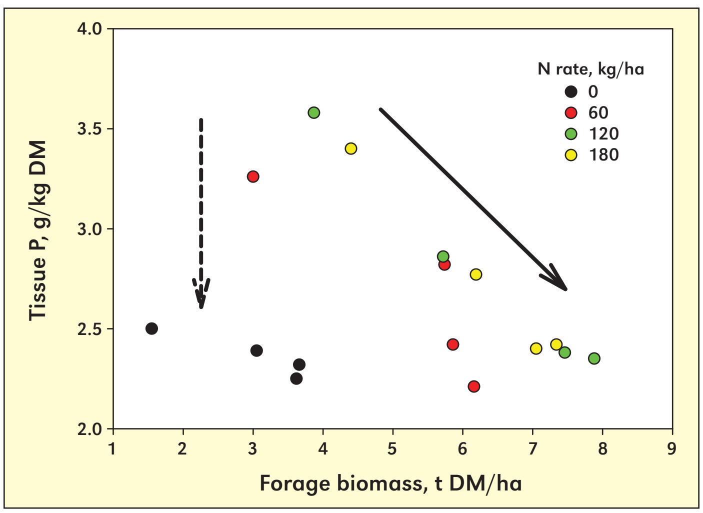

Figure 1. Example illustrating the decrease in P concentration during timothy spring growth (solid arrow) and the decrease due to a N deficiency (dash arrow). Drawn from data presented in Bélanger and Ziadi (2008).

Models of critical P concentration as a function of forage N concentration were first developed in France for perennial grasses and permanent pastures (Duru and Ducrocq, 1997), and later for timothy, the main forage grass species in eastern Canada and the Nordic countries (Bélanger and Ziadi, 2008). A model of critical P concentration [P_c; g/kg dry matter (DM)] as a function of N concentration (N; g/kg DM) was developed for timothy under conditions where P was assumed sufficient for growth (Bélanger and Ziadi, 2008):

$$P_c = 1.07 + 0.063N$$

Abbreviations and notes: N = nitrogen; P = phosphorus; P_c = critical P concentration; PNI = phosphorus nutrition index.

Experiment plots testing P fertilization for Timothy grass in 2011 at Lévis, Quebec.

A Multi-Site Experiment

Our initial research was based on timothy swards at one site in eastern Canada in situations of P sufficiency. Our model, however, had not been assessed in a wide range of crop P status, soils and climate conditions, and types of grassland swards. This led us to undertake a multi-site study to confirm our model of critical P concentration for both timothy and multi-species swards (Bélanger et al., 2017). An experiment with varying rates of P fertilization was conducted for two to five consecutive years at sites with timothy swards in Canada [Lévis (QC), Normandin (QC), and Charlottetown (PE)] and Finland [Maaninka], and at sites with multi-species swards from long-term P fertilization experiments in Switzerland [Les Verrières] and France [Ercé]. Dry matter yield, and forage N and P concentrations were measured on four dates with one-week intervals from the vegetative to late heading stages of development during spring growth. We then identified data points of forage P and N concentrations for which there was no further increase in shoot biomass with increasing P fertilizer rates; those data points characterized non-limiting P conditions.

At the four sites with timothy, the data of forage P and N concentrations under non-limiting P conditions were close to the values of critical P concentration predicted by our model initially developed for timothy (Bélanger and Ziadi, 2008; **Figure 2**). At the two sites with multi-species swards, however, the data of forage P and N concentrations under non-limiting P conditions were closer to the values of critical P concentration predicted by the model of Duru and Ducrocq (1997) than to those predicted by our model (Bélanger and Ziadi, 2008; **Figure 3**). Our results confirm the optimal relationship between forage P and N concentrations for timothy and multi-species

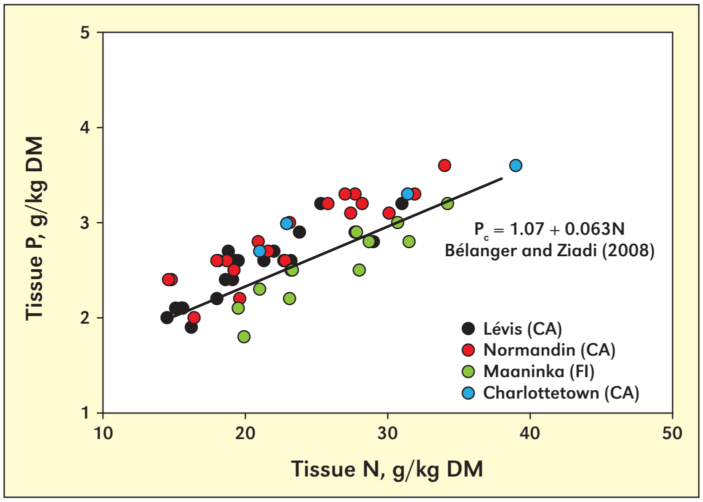

Figure 2. Forage P concentration as a function of N concentration during the spring growth of timothy grown under non-limiting P conditions at four sites along with the model of critical P concentration (P_c; line) of Bélanger and Ziadi (2008). Adapted from Bélanger et al. (2017).

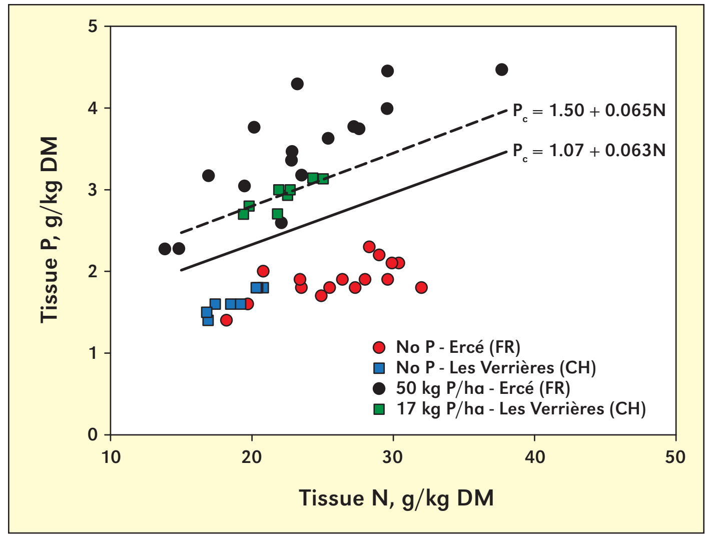

Figure 3. Forage P concentration as a function of N concentration during the spring growth of multi-species swards from long-term experiments under limiting (no applied P) and non-limiting P (highest P rate) conditions at two sites. Models of critical P concentration (P_c) are from Duru and Ducrocq (P_c = 1.50 + 0.065N; 1997) and Bélanger and Ziadi (P_c = 1.07 + 0.063; 2008). Adapted from Bélanger et al. (2017).

swards but with variations of the relationship between timothy and multi-species swards.

Limitations and Implications

Our research on forage grasses and other crops has indicated that the model of critical P concentration might not apply well in situations of severe N deficiencies or excesses (Bélanger and Ziadi, 2008; Bélanger et al., 2015a). However, producers applying adequate rates of N to optimize yield without severe N deficiencies or excesses could use our model with confidence. Establishing reliable models of P_c requires large data sets with sequential sampling during growth cycles and several P rates. In some cases [e.g., Ercé (FR)], luxury P consumption and a risk of overestimating P_c might occur if high P rates do not result in increased forage yield while increasing forage P concentration. Our timothy model for P_c was established for the spring growth and has not yet been validated for summer regrowth.

The critical P concentration is an essential tool for assessing the P status of forage grasses during the growing season and, indirectly, soil P availability. A P nutrition index (PNI) can be calculated as the ratio of tissue P concentration to P_c for a given situation. Values of PNI equal or greater than 1.0 indicate that the crop is in situation of P sufficiency, while values smaller than 1.0 indicate a P deficiency. This plant-based diagnostic method of P nutrition could be used for a predictive diagnostic aimed at adjusting P fertilization to the crop P needs during the growing season or for a post-harvest diagnostic aimed at detecting limiting factors for crops within experimental trials or fields in production. Because a P deficiency cannot be easily remedied with later applications in the same year, producers could use this tool to adjust P fertilization in the following growing seasons.

This plant-based approach of characterizing soil P availability could be an alternative or a complement to the more commonly used soil-based indicators for predicting fertilizer P requirements. In an effort to adapt this plant-based approach to field fertilization practices, we are currently investigating (i) the within-field spatial variability of the PNI in several fields in eastern Canada in order to determine the optimal number of sampling sites and (ii) the relationship between the response of forage grasses to P fertilization and both plant-based (PNI) and soil-based (soil test P) indicators of P availability. BC

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Forage Quality: Concepts and Practices

By Miguel Castillo

Forage quality is a determinant of animal performance.
Nutritive value and intake factors determine forage quality.
Forage quality estimates and indices can aid in allocation of forages among different classes of animals.

Forages play a critical role in nutrition of herbivores, and are the foundation of most livestock rations. Nutritional requirements vary among different kinds and classes of grazing animals; thus, what constitutes "high quality" forage for one animal may be "low quality" forage for another. For example, a dry cow will not require the same quality forage as a lactating cow.

Forage quality is then a relative term that is best quantified in terms of animal response (Allen et al., 2011) such as "milk in the bucket", "pounds on the scale", or "calves on the ground." Generally, the higher the quality of the forage, the greater the animal response. While the concept of forage quality is fairly simple and straightforward, in reality it is rather complex.

Laboratory analyses of forages can help to better allocate forages to groups of animals with different nutritional needs and to assess the marketable value of forage crops. Nutritive value analyses (**Figure 1**) that include estimates of digestibility, are useful in providing a first assessment of the relative potential of a forage to impact animal performance. However, animal performance is also affected by other factors, such as palatability, anti-quality constituents, and the amount of forage consumed (intake). Collectively, these factors determine the quality of forage (**Figure 2**).

Factors That Affect Forage Quality

1. Nutritive Value

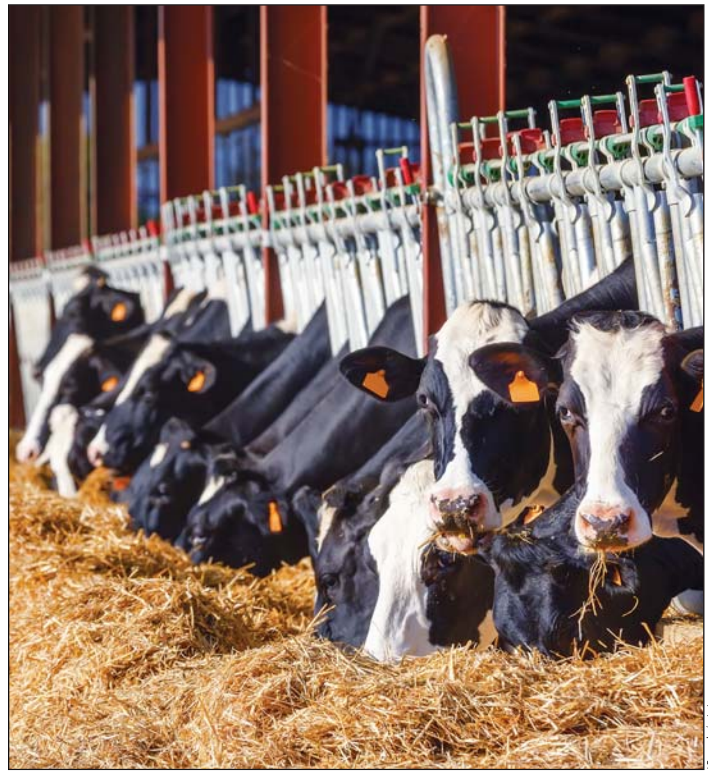
The nutritive value of forages is assessed by measuring a) nutrient concentration and b) digestibility, and by studying the nature of the end products of digestion. The three major nutrient sources found in forages are carbohydrates, proteins, and lipids, as described below.

a. Nutrient Concentration

Carbohydrates are the major source of energy for the ruminal microorganisms responsible for forage digestion in the rumen. In reality, we feed the ruminant animal by feeding the rumen microorganisms first. These microorganisms are extremely important for ruminants consuming forages because they convert the carbohydrates in the forage into volatile fatty acids, which are the major energy sources for grazing ruminants. Forage carbohydrates are divided into structural carbohydrates, found in plant cell walls, and nonstructural carbohydrates, which represent cell contents.

Nonstructural carbohydrates: These consist of a group of different types of sugars (e.g., sucrose) and reserve carbohydrates (starch and fructans). Starch is present in all forages, but fructans occur only in cool-season grasses. Starch can be found especially in seeds and roots. Fructans are located in leaves and stems, especially in the lower parts of the plant. As

Abbreviations and notes: N = nitrogen.



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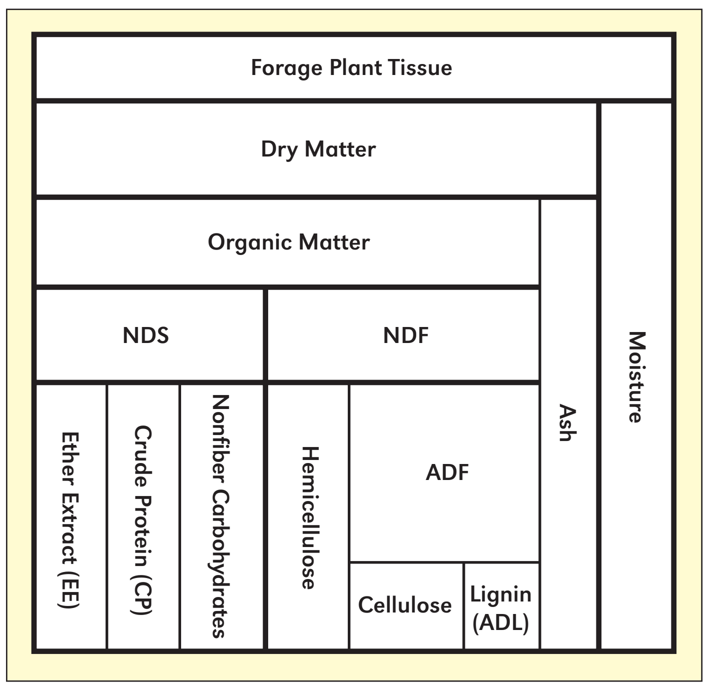

Figure 1. Schematic of laboratory analysis and chemical constituents of forages (adapted from Moore et al., 2007); ADF = acid detergent fiber, ADL = acid detergent lignin; NDF = neutral detergent fiber; NDS = neutral detergent solubles.

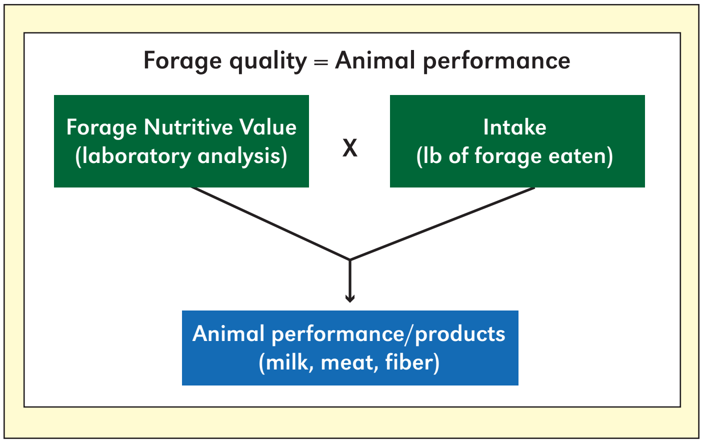

Figure 2. Factors that affect animal performance, or forage quality (adapted from Castillo and Romero, 2016).

Table 1. Nutritional composition of select forages[1].

Forage	TDN	Ash	CP	EE	NDF	ADF
	------------------		%		------------------	
Alfalfa hay[2]	60.0	9.2	19.9	2.9	39.3	31.9
Bermudagrass hay[3]	49.0	8.1	7.8	2.7	73.3	36.8
Corn silage[4]	72.0	3.6	8.7	3.1	46.0	26.6
Fescue hay[5]	44.0	6.8	10.8	4.7	70.0	39.0
Ladino clover hay[6]	60.0	9.4	22.4	2.7	36.0	32.0
Orchardgrass hay[7]	65.0	8.5	12.8	2.9	59.6	33.8
Ryegrass fresh	84.0	-	17.9	4.1	61.0	38.0
Sorghum silage	60.0	5.9	9.4	2.6	60.8	38.8

[1]Values from NRC (2000); TDN = total digestible nutrients; CP = crude protein; EE = ether extract; NDF = neutral detergent fiber; ADF = acid detergent fiber. [2]Sun-cured, early bloom. [3]Coastal, sun-cured, 43-56 day regrowth. [4]Well eared. [5]Kentucky 31. [6]Sun-cured. [7]Sun-cured, early bloom.

long as these carbohydrates are accessible to rumen microbes (through mastication or seed processing), they are rapidly and completely digested.

Structural carbohydrates: The plant cell wall is comprised of cellulose, hemicellulose, lignin, pectin, β-glucans, and polysaccharides. Lignin is a noncarbohydrate component of the cell wall and has a negative impact on digestibility. Detergent fiber analysis divides plant cell walls into neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). The NDF fraction encompasses cellulose, hemicellulose, and lignin. Pectin and β-glucans are not included in the NDF fraction and they are rapidly and thoroughly digested by microorganisms in ruminants. The ADF fraction encompasses cellulose and lignin; but if not analyzed sequentially after NDF, this fraction may contain some pectin contaminants, especially in legumes. Finally, the ADL fraction represents lignin.

Proteins are polymers formed by amino acids. Protein concentration is typically analyzed as crude protein (CP), which is a measure of the total concentration of N multiplied by 6.25 to estimate total protein concentration in the sample. In forages, nonprotein nitrogen (NPN), which includes free amino acids and ammonium compounds, typically represents 10 to 20% of the total N, but this proportion can increase during wilting and especially if the material is ensiled (Hatfield et al., 2007). The NPN can be turned into bacterial protein in ruminants, but it has little or negligible nutritive value for swine and poultry. Total CP is typically greater in legumes (15 to 25%) compared with grasses (10 to 20%). Nitrogen fertilizer can significantly increase CP content, especially in grasses. Concentrations of CP usually decrease as plants mature due to the accumulation of the fiber fraction (Hatfield et al., 2007).

Lipids are the most energy-rich fraction, typically containing 2.25 times more energy than either carbohydrates or proteins. The most relevant lipids in animal nutrition are fatty acids, triglycerides, and phospholipids. Fatty acids typically constitute 1 to 3% of forage dry matter (DM), with the majority being polyunsaturated (Hatfield et al., 2007). **Table 1** describes the nutritional composition of select forages.

b. Digestibility

Laboratory (in vitro) procedures have been developed to estimate digestibility, which is referred to in the literature as either in vitro DM digestibility (IVDMD) or disappearance. Digestibility is always highest in young immature plant tissue and lowest in mature plant tissue. Broadly, DM digestibility is usually lesser in warm-season forages, intermediate to greater in cool-season forages, and greatest in legumes (**Figure 3**). The in vitro disappearance of NDF (IVNDFD) has been identified as a major predictor of animal performance in lactating cattle. A one-unit increase in IVNDFD is associated with 0.37 lb/day increase in DM intake and 0.55 lb/day increase in 4% fat-corrected milk (Oba and Allen, 1999). The response is especially noticeable with more productive cows. Thus forages with greater IVNDFD should be allocated to the most productive animals.

2. Voluntary Intake

The amount of forage DM that animals consume when they have an unrestricted supply is considered voluntary intake. Animal performance depends on the daily intake of DM multiplied by its digestibility. Intake is the main determinant of animal performance, followed by digestibility. Animals consuming forages with greater fiber concentrations may not meet their energy requirements due to rumen fill, as shown in **Figure 4**. However, ruminants will regulate intake to meet their energy requirements when rumen fill is not a limiting factor.

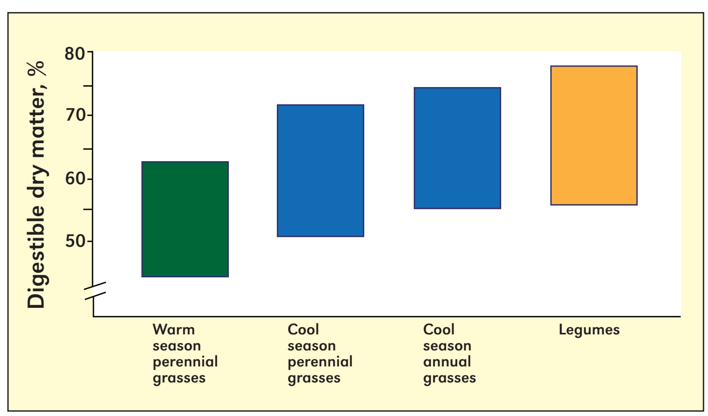

Figure 3. Digestibility ranges of major forage types (adapted from Ball et al., 2015). While the overall trend increases, ranges are wide and overlap among categories.

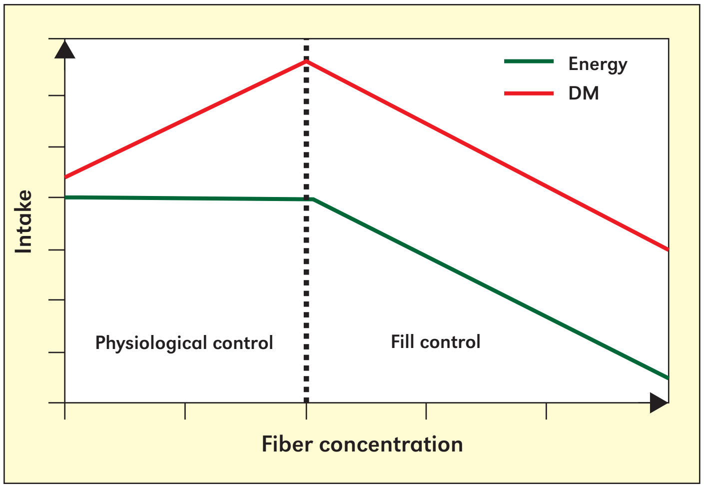

Figure 4. Relationship between fiber concentration and intake (adapted from Collins and Fritz, 2003). The first half of the figure shows that dry matter (DM) intake increases as fiber concentration in the forage increases. Energy intake remains constant, however, as a result of physiological mechanisms regulating energy metabolism (physiological control). Once ruminal fill reaches maximum capacity, DM and energy intake decrease as forage fiber concentration increases (fill control). During this stage, energy requirements are likely not being met due to high fiber concentration of the mature forage.

Unfortunately, intake is the forage attribute most difficult to measure because actual intake is a function of forage characteristics (i.e., palatability, physical properties, and nutrient availability), animal characteristics (i.e., capacity, appetite), and management (i.e., feeding, stress). Nevertheless, NDF concentration and IVNDFD can be used to predict intake.

3. Palatability

Palatability is the characteristic of a feed affecting its acceptability by animals. When given free-choice access to forages, animals can select one forage over another or parts of the same forage based on plant characteristics such as smell, texture, moisture content, height and density of sward, infestation, color, and taste. Thus palatability can also affect the rate at which animals consume forages. High quality forages are generally very palatable.

4. Anti-quality Factors

Several compounds can be present in forages that affect animal performance, cause sickness, or possibly cause animal death. These include such compounds as alkaloids, tannins, and phytoestrogens in many legumes, nitrates in many grasses, and cyanoglycosides in white clover and sorghum, as well as mycotoxins in many forages. The presence and concentrations of these compounds vary among plant species (including weeds) and are often influenced by environmental factors and animal sensitivity. For example, elevated concentrations of tannins can reduce intake and rumen digestibility. But in relatively reduced concentrations, condensed tannins can be beneficial by increasing bypass protein. In general, forages of desirable quality should not have these compounds. Or if these compounds are present, they should be at reduced concentrations that do not negatively affect animal responses.

Predicting Forage Quality

Two systems have been developed to express forage quality in terms of an index that combines both intake and digestibility. The relative feed value (RFV) index was developed by the American Forage and Grassland Council (Rohweder et al., 1978), and the relative forage quality (RFQ) system was developed by Moore and Undersander (2002). The RFQ system was developed to overcome the limitations of RFV, particularly its limited ability to compare among forage families and its inability to update prediction equations. This was achieved by introducing IVNDFD in the calculations and using total digestible nutrient (TDN) equations.

The RFQ is especially advantageous over the RFV index when evaluating grasses and grass-and-legume mixtures compared to legumes only. In both systems, a 100 value represents roughly a full-bloom alfalfa. The greater the index, the better is the forage quality. For further information on these indices see the source article (Romero et al., 2014).

Summary

Forage quality is a broad term that includes not only nutritive value, but also forage intake and anti-quality factors. Forage quality can be expressed as an index, such as RFV and RFQ. These indices can be used to appraise the potential of forages to impact animal performance. A better prediction of forage quality can be achieved by combining measurements of nutrient concentrations and ruminal in vitro dry matter disappearance. This information can help in the allocation of forages based on quality and nutritional needs and performance potential of animals, such as lactating cows and growing steers. BC

Acknowledgement

This article has been adapted from the NCSU Cooperative Extension publication available at: http://www.forages.ncsu.edu/assets/ag792.pdf

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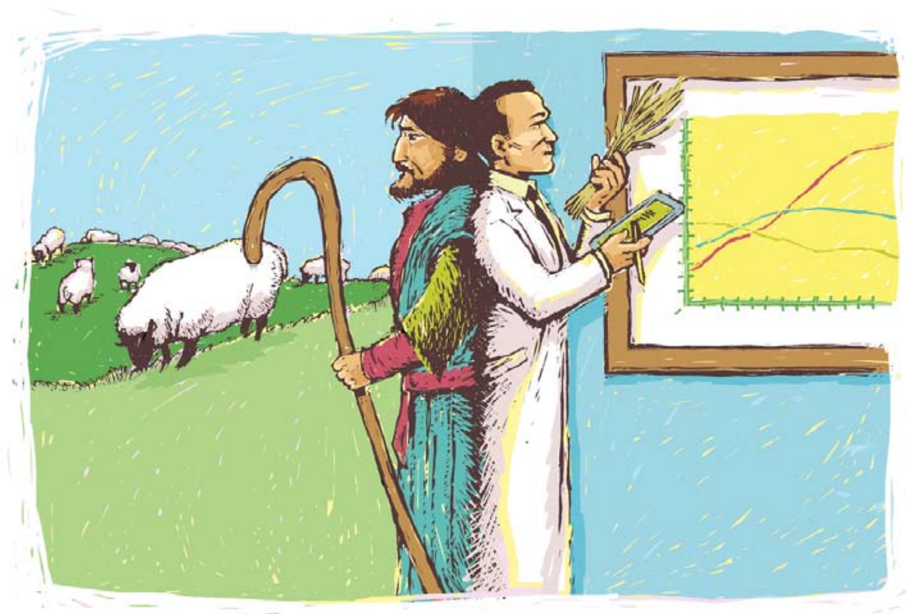
Look well to the herds

Domestication of grazing animals is thought to have begun about 10,000 years ago—and cultivation of forages some 3,300 years ago. The grazing animal-human relationship has enabled societies to expand and prosper in ways that would not have been possible otherwise, but with it has come the responsibility of animal husbandry. Shepherds and herdsmen throughout history have been portrayed as strong individuals determined to protect and feed their flocks. There are many references, for example, in the Bible concerning grazing animals, shepherds, and herds…



"…Thy servant kept his father's sheep, and there came a lion, and a bear, and took a lamb out of the flock: And I went out after him, and smote him, and delivered it out of his mouth…" (1 Sam. 17: 34-35).

"He causeth the grass to grow for the cattle, and herb for the service of man: that he may bring forth food out of the earth" (Ps. 104:14)

"Be thou diligent to know the state of thy flocks, and look well to thy herds." (Prov. 27:23)

Perhaps the most important responsibility of grazing animal husbandry is the provision of feed, especially forages. Forage has been defined as *"edible parts of plants, other than separated grain, that can provide feed for grazing animals or that can be harvested for feeding."* Given this definition, forages include a wide array of plant species and parts. Forages provide more than just feed though. These crops can provide vital soil conservation benefits, help keep rivers and streams free of contaminants, and serve as wildlife habitat. There are many management components in the maintenance of productive and sustainable forage systems, and important among these is nutrient management.

As the world's population continues to grow over the next few decades, so will the demand for animal products such as meat, milk, and fiber, and along with this will naturally come a demand for more high-quality forage and the knowledge and experience to produce it. In a time when most agronomists' attention is given to major grain crops, perhaps it's time to revisit and recount the value of forages.

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