Tree Mixtures within Integrated Farming Systems

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Abstract

Fodder trees have always played a significant role in feeding domestic animals. However, scientists have generally undervalued these feed resources mainly because of insufficient knowledge about their potential and the lack of initiative to develop appropriate feeding systems for their use. The conventional approach to the introduction of fodder trees into livestock systems is to exploit "single" species. The reality is that, in many parts of the tropical world, animals eat or are fed with "mixtures" of tree leaves. Cafeteria trials have been widely used to determine relative palatability differences within different plant species. Apart from showing the animal's preferences for a particular fodder species, they also show that, given the opportunity, ruminants will feed on mixtures of forages. Mixed foliage can be given as a supplement to rice straw and others crop residues or may constitute the whole ration. In Nepal and Indonesia, farmers traditionally feed a mixture of fodder tree leaves to their animals. This practice has been observed throughout developing countries, especially with small ruminants. There is negligible published information about the reasons why farmers feed mixtures and the choice of appropriate mixtures currently relies on the farmers' traditional knowledge. The great diversity of plant species used in Nepal may be explained by the improved nutritive value of a combination of species compared to single species on their own, with the underlying reasons being reduced toxic effects and increased variety and palatability of the diet. The use of mixtures ensures a more diverse supply of forages and therefore reduces the risk of dependence on a single plant species.

While the use of mixtures of species thus appears to be desirable, there is little scientific information on which to base practical recommendations. Recent results quantified the associative effects in vitro of mixtures of different species of Colombian fodder trees, identifying significant interactions. These suggest that there is considerable potential to develop feeding systems based on strategic mixtures that result in added nutritive value. This can be achieved by capitalising on the interactive processes, such as: protecting dietary protein with natural tannins in order to increase the amount of nitrogen which by-passes the rumen; diluting the effects of deleterious compounds; inducing associative effects that result in an increased voluntary intake; and inducing associative effects on digestibility between the components of the mixture. Appropriate mixtures of tree foliage can result in overall improvement in nutritive value and contribute to making more efficient use of the natural diversity of trees and shrubs in the tropics, and hence helping to sustain it. This paper reviews the literature on the subject and presents the main conclusions from the recent in vitro work.

KEY WORDS: fodder tree, shrub, foliage, mixture, forage, feed, toxicity, palatability, associative effect, interaction, tannin, by-pass protein

Introduction

In recent years, the scientific world has conceived the terms "biodiversity" and "megadiversity" to refer to the huge genetic reservoir in natural ecosystems. The tropical zone contains the greatest genetic diversity in the world, diversity which is expressed in the large number of vascular plants per unit area. However, this richness is being threatened by the pressure imposed by the increasing population. Of particular concern is the process of deforestation and its irreversible ecological effects. The major causes of deforestation are conversion of forest to agricultural land and cattle grazing, logging and demand for fuelwood. Recently, a range of environmentally beneficial farming practices seems to be emerging as a synthesis based on both old, proven ideas and a new understanding of natural nutrient cycles and ecological relationships (WRI, 1992). There are several examples of this new generation of farming systems in the tropics where multipurpose trees play a critical role in the sustainability of the system, by supplying protein for livestock, firewood, and sinks for carbon dioxide and controlling erosion (Preston and Murgueitio, 1992; Moog, 1992). A recent review of feeding systems used in warm climates (Roggero *et al.*, 1996) suggested that sustainability depends on making use of diverse local biological resources. This concept calls for wider use of the diversity of fodder tree species as providers of animal forage. Despite the fact that the list of trees and shrubs with potential use as fodder comprises more than 300 species, research has concentrated on very few. The danger of this over-dependence on so few species is illustrated by the psyllid epidemic (*Heteropsylla cubana*) in *Leucaena leucocephala*, and the disappearance of some valuable fodder species, e.g., *Terminalia avicennioides* in Niger, due to its replacement with *Gliricidia sepium* (Baumer, 1992). Given the current diversity of fodder trees, there is an urgent need to study and recommend promising species for specific agro-ecological environments and animal production systems, in terms of plant productivity, nutritional value and in helping to sustain this diversity.

The conventional approach to fodder trees is to study and exploit "single" species. The reality is that, in many parts of the tropical world, animals eat or are fed with "mixtures" of tree leaves. Mixed foliage can be given as a supplement for coarse roughage such as rice straw and other crop residues or it may constitute the whole ration, depending on the farming system. In Nepal, farmers traditionally feed leaves from a mixture of fodder tree species to their animals (Paudel and Tiwari, 1992) and Indonesian farmers have long been feeding mixed shrub and fodder tree leaves to their ruminants (Rangkuti *et al.*, 1990). This practice has also been observed in many other developing countries, applied especially, to small ruminants.

Nutritional Value of Mixtures of Tree Leaves

Information on the nutritive value of many trees and shrubs is scarce, yet there is even less information on the nutritive value of mixtures of leaves, since the conventional way of reporting nutritive value is a table of the chemical composition of individual feeds. There are, however, some studies on mixtures that indicate their potential.

Foliage from *Leucaena leucocephala, Calliandra calothyrsus* and their mixture (1:1) was used to supplement a diet of maize husks for goats. The daily weight gain of animals supplemented with the mixture *Leucaena:Calliandra* was greater than those animals supplemented with *Calliandra* only (22.6 and 19g). Daily weight gain of animals supplemented with Leucaena only was the highest of all (28.5), but dry matter intake (DMI) was also much greater (331.6g/day). There were no differences in the intake of Calliandra (315.2g/day) or the mixture (317.4g/day) (Phiri *et al.*, 1992).

Bosman *et al.*, (1995) fed West African Dwarf goats with *Gliricidia* sepium and a mixture of *Gliricidia sepium* combined with *Leucaena leucocephala*. (*Leucaena* only was not included in the experiment). Diets were offered at seven different levels in two experiments varying from 60 to 120g DM/kg 0.75/day, in increments of 10g, in experiment 1, and from 40 to 130g DM/kg 0.75/day, in increments of 15g in experiment 2. The maximum DM intake for *Gliricidia* and the mixture *Gliricidia:Leucaena* were, in experiment 1: 72.5 and 90 and, in experiment 2: 55.5 and 63.4g/kg 0.75/day, respectively. In both experiments *Gliricidia:Leucaena* mixtures were more digestible than *Gliricidia* alone, the difference in the second experiment being larger (10.3 vs. 3.6 percentage units). Maximum weight gain for Gliricidia was 2g/kg 0.75/day and for the *Gliricidia:Leucaena* mixture was 8.2g /kg 0.75/day, obtained when offered at a level of 80 and 106g DM/kg 0.75/day respectively. These studies indicate that a mixture of fodder tree leaves can be used to increase animal performance over that obtained when a single fodder trees species is used.

There is negligible published information on the reasons why farmers feed mixtures and the choice of appropriate mixtures currently relies on the farmers' traditional knowledge. A survey carried out in Nepal

(Rusten, 1989), showed that farmers classify forages as obhano (forages that tend to fill animal's stomach) and chiso (forages that not readily satisfy an animal's appetite and tend to lead to the production of watery dung). According to the survey the obhano-chiso status of a forage was not crucial to the evaluation of its worth. It was one attribute to be considered among others but its key importance laid in determining the mixture of forages fed. Farmers preferred to feed their animals with a mixture, "some chiso, and rather more obhano", as this was said to be optimal for animal health. For Suri farmers in Nepal, the value of any given fodder species is determined at least partially by the type of animal for which is intended, the mixture in which it is fed and the time of the year (Carter, 1992). From a scientific point of view, the improved nutritive value of a combination of species may be due to a dilution of potential toxic effects associated with particular feeds above a threshold level; the potential for synergy in digestion and/or an increase in palatability of the diet. This highlights thee important interactions which need to be considered when predicting the nutritive value of mixtures of fodder trees.

Deleterious Factors in Mixtures of Fodder Tree Leaves

Plants contain more than 1200 different classes of chemical compounds that are produced by secondary metabolism. Most of these compounds have storage, defence or reproductive functions in the plants. Many of them appear to be the natural result of the co-evolution of plants with herbivorous mammals, although some have probably evolved as mechanisms of protection against insect pests and plant diseases, in which case their effects on higher animals may be coincidental. About 8,000 polyphenols, 270 non-protein amino acids, 32 cyanogens, 10,000 alkaloids and several saponins have been reported to occur (Liener, 1980; Kumar, 1992). Tannins are the most common secondary plant compounds, but the implications for animal feeding are not entirely clear, with both harmful and beneficial effects possible (Rosales *et al.*, 1989; Mueller-Harvey and McAllan, 1992). A major characteristic is their propensity to form chemical complexes. Recent studies have revealed that tannins not only bind strongly with proteins but also with many other compounds like polysaccharides, nucleic acids, steroids, alkaloids and saponins (Mueller-Harvey and McAllan, 1992).

Farmers overcome and reduce toxicity problems by feeding mixtures of fodder tree leaves with and without sun drying. This process not only extends the choice of feeds available but also dilutes and reduces problems of palatability and side effects. Little is known about the optimum dietary levels of feeds from individual shrubs and trees (especially for those with deleterious principles), about how to reduce the incidence of deleterious effects, or about suitable mixtures in economic feeding systems for individual ruminants (Devendra, 1993). It has been suggested that the deleterious effect of secondary compounds can be overcome by the simple approach of feeding the toxic plant in a mixture with other plants, thus diluting the effective level of each compound. The effect of condensed tannins can be overcome by complexing them with polyethylene-glycol (PEG). Lowry (1990) suggested that natural PEG analogues (soluble, non-degradable polyhydroxy compounds) occur in plants, and there is the possibility of a positive interaction between tannin and PEG analogue when the two plants are fed together.

The concept of using mixtures of fodder plants with variable tannin levels to improve nitrogen utilization by ruminants (by reducing soluble protein degradation in the rumen) has been suggested. Because of the property of binding protein at neutral pH and releasing it at low pH, tannins could be used to reduce the extent of soluble protein degradation in the rumen and thus increase the amount of non-ammonia nitrogen flow to the small intestines. This concept is being tested by using the legumes *Cratylia argentea* (tannin-free) and *Flemingia macrophylla* (25.1g CT/kgDM) in CIAT, Colombia (Fassler, 1993). Intake, digestibility and nitrogen retention were measured in sheep fed low quality grass (*Brachiaria dictyoneura*) alone, low quality grass (60%) with *Cratylia argentea* alone (40%) or mixed with *Flemingia macrophylla* at two levels. Results showed that, as the proportion of *Flemingia macrophylla* increased in the mixture, there was a greater faecal nitrogen excretion and a reduction in dry matter and fibre digestibility. The positive effects found by a reduction in the amount of urea excreted in the urine were offset by the decline in digestibility. It was concluded that in formulating mixtures to supplement low quality forages it is important to consider not only tannin level but also the digestibility of the legumes used.

In another experiment at CIAT, Cratylia argentea replaced with 0, 25, 50 or 100% *Flemingia macrophylla* was fed as 40% of the total ration as a supplement to *Brachiaria dictyoneura* offered to African Hair sheep (Powell, *et al.*, 1995). As the intake of *Flemingia* increased, duodenal N flow (as proportion of nitrogen ingested) decreased. This was associated with decreasing rumen ammonia concentration; increasing proportion of nitrogen appearing in the urine, increasing loss of soluble condensed tannin and increasing protein-bound condensed tannins across the rumen. This suggests that N breakdown in the rumen was inhibited by the formation of undegradable protein-tannin complexes between feed protein and soluble tannins. There was an increment in the proportion of ingested nitrogen appearing in the faeces, indicating that post-ruminal digestion of nitrogen was inhibited. The authors concluded that, although there was no apparent benefit in terms of the overall nitrogen retention, tannins from one feed can affect the digestion of nitrogen from another feed.

Synergistic Effects of Mixtures of Fodder Tree Leaves

The amount of nutrients which a ruminant can extract from one feed can be modified by the type and quantity of other feeds consumed the same day. These interactive processes can have substantial consequences for intake and digestibility of feeds and for animal performance, in general. Associative effects between components of a mixed diet occur when, as a consequence of the interactive processes, the nutritional value of the mixture is not equal to the sum of its individual components. These effects can be positive (synergistic) or negative. Most studies of associative effects in terms of digestion relate to the effect of a source of rapidly fermentable carbohydrates (like barley or maize silage) on roughage digestion. There are some studies of the effect of mixtures of temperate (Cassida *et al.*, 1994; Glenn, 1989) and tropical (Brown and Pitman, 1991) grasses and legumes but until recently, none on the effects of mixtures of fodder tree leaves on digestion.

Rosales (1996) studied the nutritive value *in vitro* of mixtures of fodder tree leaves in order to understand the factors that determine their associative effects and the interactions between tannins and other feed components. The results of this study suggested that associative effects of mixtures of tree leaves are governed by the degree of synchronisation of the fermentation rates of the different components of the mixture and these, in turn, are dependent on the fermentability of their chemical constituents.

The fermentation of tree leaves (20 tropical fodder tree and shrub species) was studied with two contrasting media, with zero and high nitrogen contents, using a pressure transducer to measure the effect. This enabled the chemical constituents of fodder tree leaves that had the most effect on the fermentation, and the time at which their importance was greatest, to be identified. An initial understanding of the associative effects was achieved by studying mixtures of pure chemical entities.

Significant associative effects for mixtures (50:50) of fodder tree leaves and carbohydrates were shown to occur. Two types of response were identified: the first was exponential and characteristic of mixtures of high fermentability; the second was sigmoidal and was characteristic of mixtures of low fermentability. These two responses in associative effects were similar to those obtained with mixtures of pure carbohydrates and proteins where the synchronisation of the fermentation rates of the components occurred in the early and late stages respectively. The late availability of nitrogen was due to the nature of the protein itself or to the presence of phenolic compounds. Associative effects tended to be greater in mixtures with carbohydrates of low to medium fermentability, especially towards the end of the incubation period. The mode of action was a decrease in the fermentation rate and an increase in the lag phase. The associative effects with highly fermentable carbohydrates were higher at the beginning and decreased towards the end of the fermentation. The mode of action was an increase in the rate constant and a reduction in the lag phase.

Phenolic compounds in the leaves were shown to affect the fermentability of both carbohydrates and proteins. The effect was greater with carbohydrates of medium to low fermentability. On the other hand, they were shown to react with both soluble and insoluble protein. The effect of condensed tannins in the leaves was a depression in the fermentability of their mixtures with carbohydrates. This depression was greater in mixtures of low fermentability. Forages with phenolic compounds showed positive and negative effects. These effects were possibly due to synchrony or asynchrony in the release of protein.

Associative effects of mixtures of tree leaves themselves were shown to occur. By studying the fermentation rates, it was possible to characterise these effects in terms of the time at which the synchrony occurred and in terms of the fermentability of the components. The synchrony occurred at different times during the incubation period and was characterised by changes in the fermentation kinetics of the mixture. The response was also identified as sigmoidal or exponential in shape, the latter being more common. Associative effects were shown to vary with time and with the level of nitrogen. They were shown to be governed by a synchrony of the fermentation rates of the single components of the mixture.

Various authors have proposed that microbial growth efficiency and hence animal performance may be improved by a synchronisation of energy and nitrogen supply to the rumen. The importance of this synchrony to the associative effects of mixtures of forages has been proposed. Glenn (1989) suggested that the mode of action of the associative effects in mixtures of lucerne (*Medicago sativa*) and orchardgrass (*Dactylis glomerata*) was a synergism in rumen fermentation of NDF and N from the two species.

Findings by Rosales (1996) suggested that, although the mode of action is a synergism in the fermentation, the components involved are more than those suggested by Glenn. The main chemical components involved in the associative effects are proteins (at least two fractions in each component of the mixture), sugars, starch and cellulose. Phenolic compounds play a role by affecting fermentation rates and hence synchrony. The difficulty of predicting the associative effect from the chemical composition derives from the fact that the effect is produced by the interplay of all components. The individual fermentability of the chemical components (which varies between species) determines when the synchrony occurs and this determines the type of associative effect produced. According to Rosales (1996), the characterisation of the fermentability of individual nutrients may be more dominant in predicting associative effects than the chemical composition. Mixtures of leaves of plant material high in rapidly fermentable carbohydrates with material high in soluble and fermentable nitrogen showed the greatest effect of all. The mixtures of plant material with the highest phenolic contents and with the highest soluble and insoluble protein showed important associative effects. However, in the case of the high nitrogen conditions, when urea is increasing the fermentation rate, associative effects are more difficult to predict from the chemical composition as the synchrony depends on the fermentability of the individual components. This highlights the importance of characterising the fermentability of the chemical components in the leaves.

Sinclair *et al.* (1993) developed a "synchrony index" based on the fermentation characteristics of feeds that is calculated from the hourly release of nutrients to the rumen microbes. For example, a rapidly released unit of nitrogen could be used with a slowly released unit of carbohydrates that had been eaten by the animal some hours previously. This index has been developed using feedstuffs rich in energy and protein, like winter barley and fish meal, and the diets are formulated to take account of total DM intake, times of feeding and outflow rate of solids from the rumen. In the case of tree leaves, which are chemically more complex feedstuffs, the synchronisation of rates may be more critical than that of more homogeneous feeds. Nsahlai *et al*. (1995) calculated the synchronisation indices of the release of nutrients of twenty fodder trees accessions. They found that, from the point of view of the synchronisation of the release of soluble and insoluble nutrients (N and OM), there was generally a moderate to poor synchronisation of the fermentation of N and OM because nitrogen was released in excess. This is a disadvantage if the plant species is fed as a sole food but these indices may be useful to design or predict appropriate mixtures of tree fodders. The development of synchronisation indices for mixtures of fodder tree leaves is an important step towards the prediction of their associative effects. However, such indices are affected by the rate of passage and thus, an associative effect observed *in vitro* may not show, or it may change, in an *in vivo* situation because the synchrony did not occur due to differences in the rates of passage. Measurement of rate of passage is expensive, time-consuming and has to be conducted in vivo and thus current research at NRI is exploring the possibility of using palatability as a simple index with which to predict rate of passage (Romney, unpublished observations).

Before leaving consideration of associative effects in the rumen, consideration should be given to whether positive or negative associative effects should be actively sought. In the case of fodder tree leaves, a negative ruminal associative effect could be related to a dietary protein being protected from fermentation by tannins and thus providing bypass protein. In this case, a negative effect on digestibility can be a positive effect in terms of animal performance. The results of Rosales (1996) showed negative associative effects when tannin containing plants were mixed with plant material without tannins but high in soluble protein. Although important in magnitude, these effects were not statistically significant at the levels used. Other levels should be tested. The only case of a significant negative associative effect was found for a mixture of plant materials that there were both high in tannins. This indicates an antagonism of the two components in terms of fermentability but the effect on protein was not evaluated.

Effects on Voluntary Intake

The magnitude of the associative effects found in the in vitro study of Rosales (1996) varied from 4.4 to 18.1%, but these will only be turned into positive effects on animal performance if intake is maintained or increased. Ruminants (especially goats) when left to browse ad libitum will select a varied diet. Cafeteria trials have been used widely to determine relative palatability differences between species of shrubs and fodder trees. Apart from showing the animal's preferences for particular fodder species, they also show that given the opportunity, ruminants will consume more of a mixture of forages than of a single diet component. This was observed by Le Houerou (1991) who evaluated the intake of 9 species of native and exotic shrubs offered either alone or in a mixture to ewes in Libya. Thus, total intake of mixtures is likely to be higher, but in addition, different dietary components also offer the potential for feed sequencing and feed selection.

To give some idea of the potential impact which the feeding of mixed diets can have on animal performance, either through effects on digestibility and/or intake, Table 1 shows the results of experiments to compare increasing levels of fodder tree supplementation in different species of ruminants. These feeding trials with fodder tree leaves were designed to establish the optimum ratio of supplementation of a basal diet or to study substitution effects on intake. The data show that in all cases there was an associative effect on DM intake and that, bearing in mind the increased DM intake, there may be associative effects on DM digestibility between the basal diet and the leaves from a single fodder tree species. Further associative effects would be expected to arise from using leaves from mixtures of fodder tree species.

Implications of the Mixtures of Trees for the Farming System

Species mixtures may have benefits to the farming system over and above those for the animal component. A mixed stand of fodder tree species may have advantages over plots of single tree species in terms of greater biomass production (in strata) and a greater contribution to multiple uses. Growing mixed stands may also reduce the incidence of disease, since tree species grown as pure stands are more prone to disease. There are reports of 23 different common diseases for the Acacia genus for example without including those which are species specific. *Leucaena* species are prone to 16 common diseases, 56 in the case of *Cassia* species to mention some. In the case of *Gliricidia*, there are only 6 diseases common to the genus but *Gliricidia sepium* is prone to a total of 38 different diseases (NRI, 1994).

Designing the best species combination for a mixed stand of trees can prove difficult. As is the case for mixtures of forages for the animal, when plants grow in proximity to each other they interact in positive ways (complementarity) or negative ways (competition). Plants compete for three main elements: light, water and nutrients.

Table 1: Effect of increasing levels of forage tree legume supplementation on intake and digestibility by cattle and goats

Browse Species	Animal species	Basal Diet	Level of browse (%DM)	Voluntary Intake g/kg/day	Dietary DMD %
Leucaena leucocephala	Cattle	Grass	0	20.2	42
			20	26.1	44
			40	28.8	46
			60	28.8	44
			100	22.1	51
Leucaena leucocephala	Goats	Barley straw	0	17.9	48
			33	29.5	60
			65	30.9	57
			100	27.1	62
Albizia chinensis	Goats	Hay	0	18.9	46
			27	27.8	56
			61	27.4	49
			100	24.6	48
Sesbania sesban	Goats	Barley straw	0	17.7	48
			33	28.7	61
			66	31.7	64
			100	27.8	64

DM = Dry matter
DMD = Dry matter digestibility
Source: Norton 1994.

An appropriate mixture of species should perhaps include one species with a deep root system, complemented by another with a more extensive one; one species that needs plenty of sunlight and another which can grow under the canopy of the first one, for example. A combination of a legume with a non-legume species can be advantageous as well as including trees for human food production (fruits) or livestock consumption (pods and leaves). According to Sanchez (1995), the biophysical bottom line of agroforestry is how to manage the interaction for light, water and nutrients between the tree component and the crop and/or livestock components for the benefit of the farmer.

Examples of farming systems in which a mixture of fodder trees and shrubs plays a central role or is an integral part of the system are scarce. A good example of such a system is a multi-strata system. Nitis *et al.*, (1990) described a three-strata forage system in Bali. The system involves grasses and ground legumes (first stratum) for use during the wet season, shrub legumes (second stratum) for use during the middle of the dry season, and fodder trees (third stratum) for producing feeds during the late dry season. *Gliricidia* and *Leucaena* constitute the second stratum and *Ficus*, *Lannea* and *Hibiscus* trees constitute the third stratum. The system consists of 0.16 ha cash crop for human use and 0.09 ha pasture, 2000 shrub legumes and 42 fodder trees to produce feeds for livestock. Animals are fed on varied mixtures of forages throughout the year. Mixtures of fodder tree leaves can constitute as much as 75% of the diet during the dry season. Effects of associating grasses, legumes, shrubs and trees have been evaluated both from the agronomic and nutritional points of view. The three strata forage system increased forage and fuelwood production, live weight gain, stocking rates and reduced soil erosion when compared with a non strata system. Initial agronomic evaluations of another multi-strata system consisting of the herb *Symphytum peregrinum*, the shrub *Urera baccifera* and the trees *Trichanthera gigantea* and *Inga edulis* are being carried out by CIPAV.

Conclusions

The potential advantages of establishing mixtures of fodder tree species on farms when developing new feeding systems have been described in this paper. However, researchers still need to develop a series of principles from which recommendations can be developed. Since animal production in the tropics is facing new challenges, especially trying to balance food security and conservation goals, these principles need to relate to animal productivity, the productivity of the farming system as a whole and the maintenance of biodiversity.

The development of feeding systems based on mixtures which make better use of available resources and enable farmers to meet their objectives requires further research to address the questions listed above, preferably with the application of lateral thinking! Analysis of a mix of field observations and scientific experiment will help to establish principles and lead to recommendations which can be adapted by extension workers and farmers to a range of ecosystems and economic climates.

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