

FUNCiTREE

TECHNICAL BRIEF

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Models of trait-based agroforestry multi-functions

Carlos Pérez Carmona
Graciela M. Rusch
Cipriano Rivera
Cristóbal Villanueva
Fabrice DeClerck
David N. Barton

COOPERATION

www.funcitree.nina.no

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Graciela M. Rusch

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CONTACT INFORMATION
Graciela M. Rusch: graciela.rusch@nina.no

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Carlos Pérez Carmona
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1 Approaches to analyse multi-functions in agroforestry systems

One of the FUNCiTREE's primary goals has been to collect evidence on and to demonstrate the multiple functions that agroforestry (AF) systems provide in the case studies. We also aimed to show how the various functions in the AF system are associated to particular attributes (values or types of functional traits) of the trees that are part of these systems.

The Ecosystem Services concept provides a conceptual framework to understand multiple functions and their interactions, it highlights that there are functions that are synergetic, but that there may also be trade-offs among them. Whereas it is important to identify synergies in order to enhance the multi-functionality of agroforestry sytems, the acknowledgement of trade-offs is equaly important since in these cases, decisions must be made among one or several choices.

Trade-offs among functions may occur at different levels, at the farm level, but also among different interest groups. Decision-making support tools, are packages of methodologies and softwares that can help to identify trade-offs and also to visualize the consequences of decisions on particular choices.

FUNCiTREE used Bayesian Belief Networks (BBN) as the main tool to address the analysis of multiple functions, with a potential to use these models as graphical decision-making tools. Some advantages to using BBNs for modelling scientific knowledge of tree multifunctionality in agrosilvopastoral systems (ASP) include:

- The possibility of treating uncertainy explicitly
- That it enables to explore the consequences of different decisions, not only from the perspective of expected values, but also with regard to the risks of undesirable outcomes.
- The method is suitable for small and incomplete data sets, which can be updated easily when new data are available.
- The method simplifies the processes of engaging stakeholders in participatory processes

After a BBN is completed, it can be used to simulate different cases based on the conditional probability distributions used to build the network. At a second stage, we applied rank-correlation methods on simulated BBN outcomes to establish the occurrence of synergies and trade-offs among functions.

A second approach adopted by FUNCiTREE to analyse multiple functions in AFS was through standardized synthetic indices for each function. According to this, the calculation of summary indices that reflect multi-functionality such as functional diversity (FD) can help to discern if more functionally diverse plant communities can provide a greater and more stable provision of ecosystem functions.

2 Assessment of multi-functionality through BBN and correlation analysis

We illustrate this approach with traits, species and functional response data in the FUNCiTREE data base obtained on the Potou case site and from the CIRAD database on species chemical composition.

2.1 AF tree functional grouping

The data from Potou were collected on 106 individuals of 23 species occuring under two different environmental conditions, in salty soils and in non-salty soils. The trees or the species were clustered in functional groups according to different traits, which were associated with the three ecological functions: grassland productivity, soil properties and fodder provision (Table 1) using hierarchical clustering, in some cases in combination with ordination techniques. The structure of the data allowed creating functional groups based on individuals for the grassland productivity and soil properties functions, while we used species averages for the fodder provision function.

Table 1: Traits used to group trees according to their potential to affect understorey productivity, fodder quality and soil chemistry

Grass productivity	**Soil properties**	**Fodder provision**
Specific leaf area (SLA)	Tree height	Acid detergent fiber
Maximum Leaf area index (LAI)	SLA	Acid detergent lignin
Minimum LAI	Legume /non-legume	Crude protein
Leaf phenology		Gas test value
		Neutral detergent fiber
		Soluble Nitrogen
		Total Phosphorus
		In vitro degradation of Organic matter
		Content of tannins

2.2 Ecological responses

The responses of the grassland and the effects of the trees on the soils were assessed by measuring above ground productivity and soil chemistry variables, both under the tree and in an adjacent area of grassland, beyond the influence of the tree crown. We used the Relative Interaction Index (RII), to quantify the net effect of the tree on these response variables. RII values can range from -1 (negative effects on productivity or soil fertility) to +1 (positive effects). In order to include the responses values in the BBN, the RII values were divided into 5 different categories. The interpretation of these categories for grassland producitivity is:

1) RII < -0.2 Strong competition
2) -0.2 < RII < -0.05 Moderate competition
3) -0.05 < RII < 0.05 Neutral effect
4) 0.05 < RII < 0.2 Moderate facilitation
5) RII > 0.2 Strong facilitation

In the case of soil fertility, 5 response variables were included in the analysis, i.e. soil pH, carbon and nitrogen content, conductivity, and content of mycorrhiza sprores. In these cases, category 1 would indicate a great decrease of the response variable under the tree canopy, while category 5 indicates a great increase.

2.3 Bayesian Belief model of AF multiple functions

We built the multiple function model based on sub-networks representing the effect of the different tree species on each of the three functions. The sub-networks had the following assumptions:

I. *Tree functional group - grassland productivity*: i) the effect of the trees on grassland productivity depends on the characteristics of the tree functional group. ii) the outcome of the tree-grassland interaction could be either positive or negative depending on the balance between the magnitude of facilitative and competitive effects. iii) the balance between facilitative and competitive effects is a function of the environment. In general, facilitative effects are expected to be predominant in harsh environmental conditions and competition should prevail when resources are more abundant, but this general pattern might be modified by the functional traits of the trees.

II. *Tree functional group – soil fertility*: i) the effect of the trees on 5 soil properties (i.e. soil pH, carbon, nitrogen, conductivity and content of mycorrhiza spores) depends on the characteristics of the tree functional group, ii) the net effect of the tree on the soil could be either positive or negative, based on the calculation of the RII, and iii) the net effect of the trees on soil properties is a function of the environment.

III. *Species functional group – fodder preference/consumption by livestock:* the characteristics of the tree functional group, which were based on several chemical composition traits summarized using ordination techniques, determined the preference of three different livestock species (cattle, sheep and goats) for each of the tree species.

A detailed description of the methods of functional group clustering and examples of the outcomes in terms of responses are provided in FUNCiTREE Technical Brief no. 4 “Models of trait-based AFS for single functions”.

The grassland productivity and the soil fertility sub-networks accounted for intraspecific variability of traits; in these cases, individual trees were clustered into functional groups according to their particular (measured) trait values. We were also able to track the responses of grassland productivity and soil variables to individual trees, and had information of the location of the tree, that enabled to associate the response to the environmental condition (salty and non-salty soils). In the case of the fodder quality function, we used species average data both for the traits and for the animal preferences, and therefore the environmental characteristics do not play a role in this sub-network. The three sub-networks were linked through the variable (node) “species” (Fig. 1).

2.4 Frequency distributions in the data set

The majority of the trees in the survey (78%) occurs in non-salty soils (Niayes) (Fig. 1), reflecting the abundance of each soil type in the dataset. In the case of tree-grassland interactions, more than half (55%) the observations indicate high positive impacts of trees on grassland productivity, and there is also a a relatively high proportion of observation with moderate increase in cover under trees. Regarding the soil, the majority of the observations indicate high positive impacts of trees on soil carbon, nitrogen content and conductivity, and either some reduction (ca 30%) or no effects (65%) on soil pH. The presence of trees appears to reduce the amount of mycorrhiza spores; 49% of the cases showed a strong negative effect. Among the species in the fodder provision data set, there is an even distribution of preference classes defined by experts, and those based on knowledge of cattle and sheep consumption; and an over-representation of species preferred by goats (ca 78%).

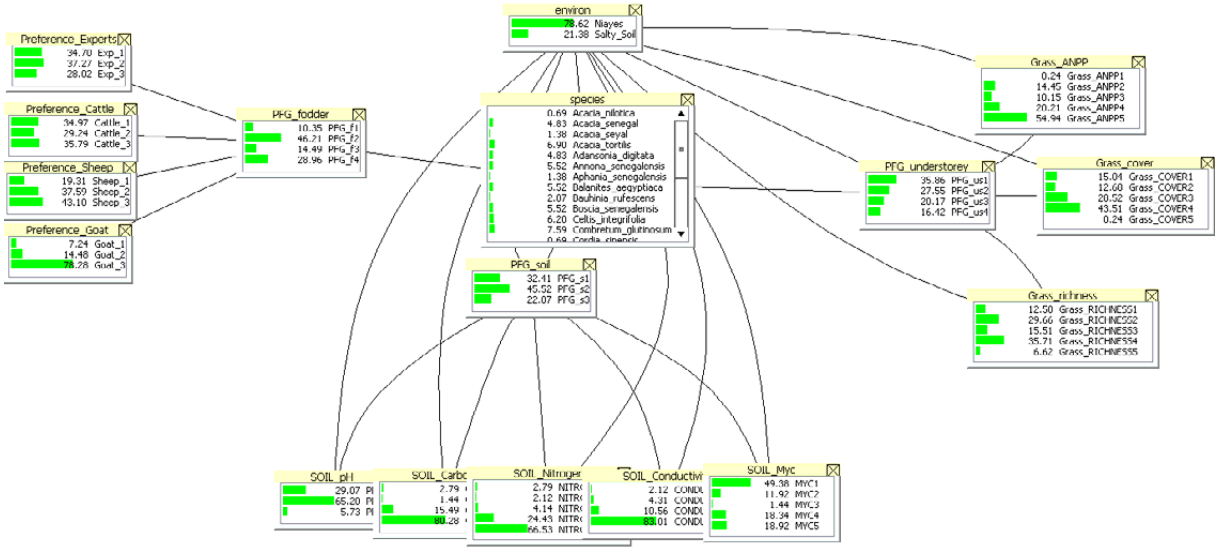


Figure 1: Bayesian Belief Network (BBN) representing three AF functions, tree-grassland productivity, tree-soil fertility and species – fodder quality. The sub-networks are linked through the node 'species'. The tables indicate the frequency distributions of the classes in each node.

2.5 Analysis of the co-variation of functions

Examination of the covariation patterns among the different functions can be used to indicate the existence of trade-offs, which should be associated to a negative correlation between the levels of two functions, and synergies, indicated by positive correlations. Such an examination can be very helpful when deciding among different management alternatives, because they give an insight into the possible effects that a management option can have on the different functions; for instance, when selecting tree species that maximize grassland productivity, other important functions such as fodder quality may decrease. After establishing the BBN, we created a set of 10 000 simulated trees that complied with the conditional probability tables that have been used to create the network. The creation of such dataset permited the examination of the structure of the data with a focus on the covariation structures among pairs of functions. In order to explore the covariation structure, we conducted rank-correlation tests among all the possible pairs of functions in the simulated dataset based on the BBN values.

The analysis shows a high degree of independence among most of the functions, and especially very few negative interactions among the functions (Fig. 2). In 78% of the cases, there were positive but very weak correlations among the response classes from the different functions. The positive effects of trees on grassland productivity were independent of the effect of trees on soil properties. This finding is in agreement with the results obtained using regression models that showed the net effect of trees on grassland productivity was independent on the net effect on soil carbon. In this analysis, tree size, was the tree trait that most significantly (negatively) affected grassland production. These results are also in agreement with the results for the individual functions, which showed that while the effect on grassland productivity depends on the interaction between environment and functional group, the effect on soil features such as carbon or nitrogen content is positive regardless of other factors (FUNCiTREE Technical Brief no. 5).

Similarly, the net effects of trees on the soil and on grassland productivity were also generally unrelated to the preference of the fodder by animals. The only noteworthy correlations observed were among preference classes for the different livestock species. The preferences of sheep and goat were negatively

correlated with those of cattle, suggesting that management strategies that seek to simultaneously maximize the preferences of the three livestock species might be difficult to achieve.

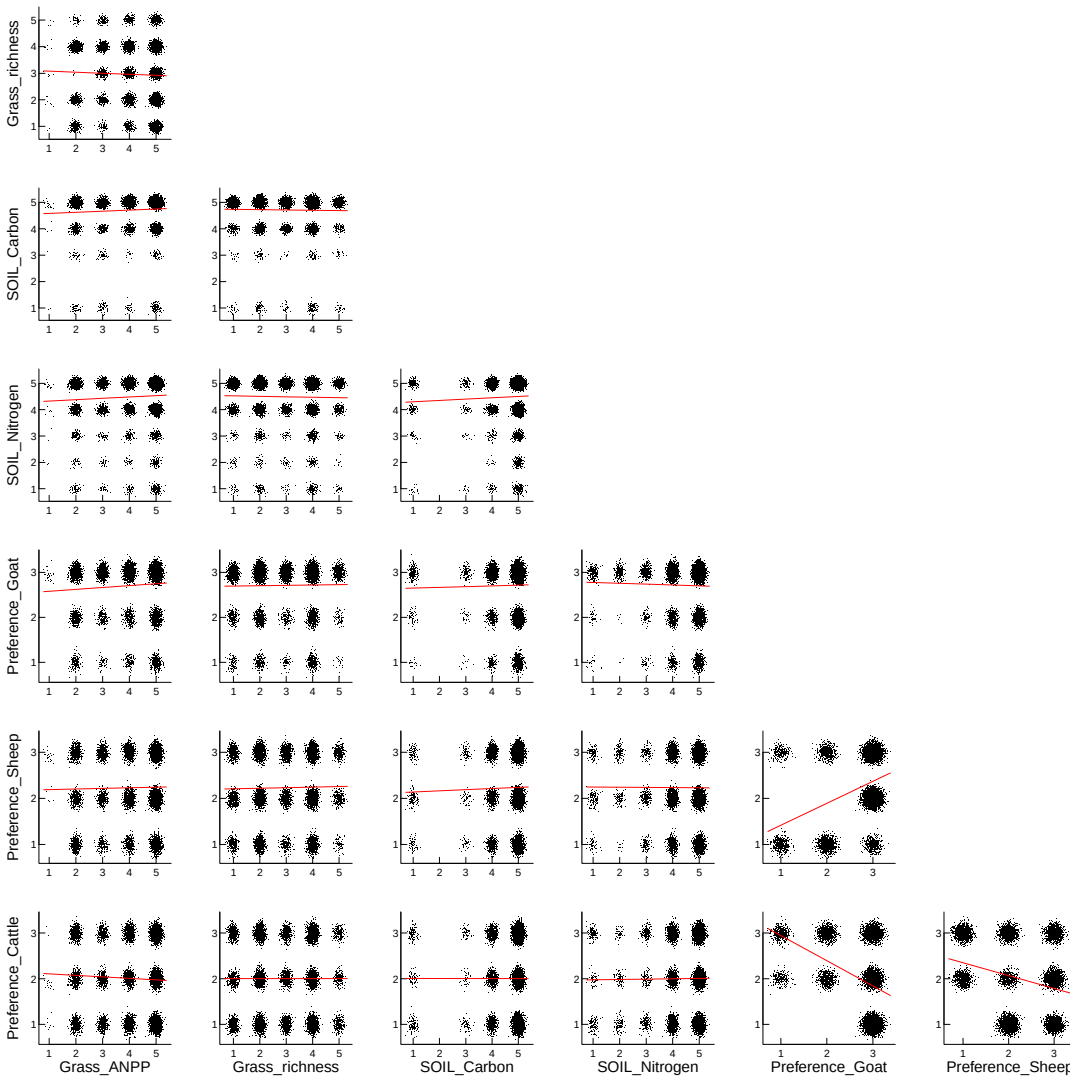


Figure 2: Rank correlations diagrams between classes of response variables based on 10 000 simulations of Bayesian Belief Neworks outcomes.

3 Functional diversity in AFS

FUNCiTREE analysed multi-functionality of paddocks in the farms occurring in the area of Rivas by assessing the composition of trees that grow scattered in the paddocks and in live fences, the two main silvopastoral elements in the landscape.

Five ecosystem services or functions were included in the analysis:

I) *Provision of habitat for wildlife*. The degree to which a paddock contributed to habitat provision was determined through a biodiversity index calculated on tree species abundances.

II) *Carbon fixation*, assessed through a dasometric equation using the FUNCiTREE database.

III) *Fodder quality*, assessed as an index of nutritional functional diversity based on data on dry matter, crude protein, contents of nitrogen, phosphorus and calcium.

IV) *Pasture shading*, assessed through dasometric variables, tree crown size, tree cover and paddock area.

V) *Provision of feed in the dry season*, based on binomial classes of: species that provide forage, species that provide fruits and species with re-sprouting capacity.

Using clustering techniques, the paddocks with dispersed trees and live fences were grouped according to the level of provision of the five services and the structure of the tree cover.

3.1 Functionality of paddocks in the Rivas landscape

Paddock types in the Rivas area differed considerably in terms of functionality. Four groups were identified with statistically significant differences in the level ecosystem services provision (Table 2).

Table 2: Levels of ecosystem services provision by type of paddock area with dispersed trees in Rivas. Habitat provision, carbon fixation, forage quality, pasture shading and provision of cattle feed in the dry season

Paddock type	Habitat	Carbon	Fodder quality	Pasture shade	Feed dry season
1	**0.36 a**	**0.10 a**	**0.64 c**	**0.05 a**	**0.73 c**
2	**0.40 a**	**0.22 ab**	**0.11 a**	**0.10 a**	**0.17 a**
3	**0.54 b**	**0.39 b**	**0.37 b**	**0.20 b**	**0.38 b**
4	**0.60 b**	**0.37 b**	**0.37 b**	**0.91 c**	**0.41 b**

Table 3: Levels of ecosystem services provision by live fence type in Rivas. Habitat provision, carbon fixation, forage quality, pasture shading and provision of cattle feed in the dry season

Live fence type	Habitat	Carbon	Fodder quality	Pasture shade	Feed dry season
Simple	**0.39 a**	**0.37 a**	**0.46 c**	**0.06 a**	**0.17 c**
Complex	**0.55 b**	**0.75 b**	**0.70 a**	**0.06 a**	**0.23 a**

An overall index of ecosystem service provision was calculated for the paddock area with scattered trees and for live fences, showing large differences in multi-functionality in these two elements of the silvopastoral system in Rivas (Figs. 3 and 4). There were also large differences in the degree of multi-functionality among paddock types. (Fig. 5).

Paddock area with dispersed trees of Type 2 had the lowest global index of ecosystem service provision, less than half the value of the index for paddock area Type 4 (Fig. 3 and 4)). Type 2 appears to score particularly low in the services associated with livestock production, i.e. the provision of fodder of high

quality, shading of the pasture and feed in the dry season. Paddock area Type 2, is characterized by intermediate tree cover and density, comparatively few but large individuals, with wide canopy and high individual basal area, but low basal area at the paddock level. Tree species richness is low, which may be partly related to the size of the individuals.

There was also a strong constrast between the two live fence types, with complex live fences providing substantially higher levels of provision of the ecosytem services in the study. Simple live fences are formed by 1 or 2 tree species, whereas the complex types had, in average, more than 4 species /ha. The number of individuals /ha was aproximately three times larger than in simple fence types.

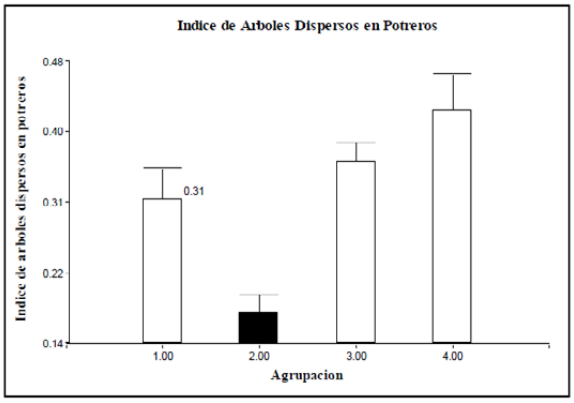


Figure 3: Global index of multi-functionality in the paddock area with scattered trees found in Rivas.

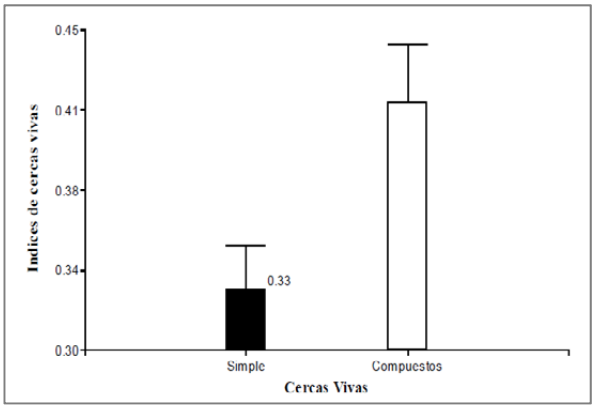


Figure 4: Global index of multi-functionality in two types of live fences, simple and complex, ocurring in Rivas

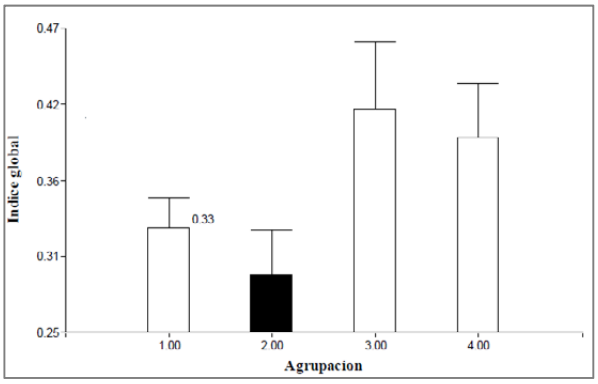


Figure 5: Global index of multi-functionality in four paddock types found in the area of Rivas.

3.2 Consequences for management and AF system adaptation

The dispersed trees found in the paddocks in the area of the study are most commonly remnants after the clearing of the forest when livestock ranching was established, and possibly a result of natural regeneration, although grazing and browsing, trampling and weeding, generally hinder natural establishment of trees in the paddocks. Consequently, dispersed trees in paddocks are generally not managed actively with agroforestry practice.

Live fences, on the other hand can be managed more actively, and given the large differences found in the level of service provision and multi-functionality by increasing the species richness with an appropriate choice of species there seems to be substantial potential for improvement with the management of live fences. Live fences can provide shade for the animals, fruits, firewood, timber, and fix considerable amounts of carbon. Recent studies in Central America (Honduras) show that 70% of the firewood used in the livestock farms are produced in live fences and in paddocks. In Rivas, on the other hand, the use of live fences is limited, generally fences are constructed with poles. With an adequate design and management, live fences have the potential to provide all year fodder. Currently, even when live fence trees have the potential to provide fodder, this resource is under-utilized.

FUNCiTREE

Functional Diversity:
An ecological framework for sustainable and adaptable agro-forestry systems in landscapes of semi-arid ecoregions.

Based on the principles of functional ecology, FUNCiTREE addresses the provision of multiple services of silvopastoral systems (SPS) in semi-arid regions in Africa and Central America. FUNCiTREE aims to provide farmers in the regions with a portfolio of regionally suitable tree species that are capable of providing multiple services. The project integrates theories and concepts from agroforestry and ecological science and will provide a scientifically based model for the design of modernized SPS.

NINA (Norway): The leading research center in Norway on applied ecology, emphasizing the interaction between human society, natural resources and biodiversity

CATIE (Costa Rica): A regional research and education centre about agricultural sustainability, environmental protection and poverty eradication

WUR (The Netherlands): Internationally leading university in agricultural Almeria has a focus on organism responses to drought, ecological interactions, biodiversity conservation, desertification, and soil science

CIRAD (France): Research on agro-ecosystems for international sustainable development, environmental, and climate research

CSIC (Spain): Research at the Arid Zones Research Station,

ISRA (Senegal): Priority areas relate to agronomic, animal and forest production, and rural economy

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