Agroforestry Systems **51**: 77–84, 2001.

Estimates of above-ground biomass and nutrient accumulation in *Mimosa scabrella* fallows in southern Brazil

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Key words: bracatinga, improved fallow, relay-intercropping, self-thinning, sequential systems

Abstract

Naturally regenerated stands of bracatinga (*Mimosa scabrella* Bentham) are harvested for firewood after six to eight years of unregulated growth, debris burnt and the area planted to one cycle of intercropped maize (*Zea mays* L.) and beans (*Phaseoulus vulgaris* L.). Burning breaks dormancy of bracatinga seed (> 80% germination) marking the onset of a new fallow-crop cycle. This production system has been practiced for nearly 100 years in Southern Brazil, covering some 60,000 ha in 3,000 small farms. An estimation of above-ground biomass and nutrient accumulation was made using literature data on stand age, population numbers, tree sizes, tree biomass partitioning and concentration of major nutrients in tree tissues. A simple simulation model, used to quantify above-ground nutrient pathways and their temporal dynamics, confirmed that six to eight years is the optimal rotation length. Biomass and nutrients deposited onto the soil, peak at stand age six years, which may result in significant soil fertility improvement prior to crop planting. At year six, estimated total above-ground biomass amounts to 83 Mg ha^{-1}; 44 Mg ha^{-1} available as firewood and 39 Mg ha^{-1} to be returned to the soil. Roughly half the amount of nutrients fixed in the above-ground bracatinga biomass would be exported in firewood and subsequent grain crops.

Introduction

Planted, short-term (one to three years) fallows for soil fertility management in annual crop production are now under intense scrutiny in various regions of the tropics, using woody, leguminous shrubs like *Sesbania sesban* (Kwesiga and Coe 1994; Swinkels et al. 1997). Herbaceous, slash-mulch, naturally regenerated fallows for bean (*Phaseolus vulgaris*) production in Central America have been recently reviewed (Thurston 1997). Planted, medium-term fallows for soil improvement and firewood production with *Gliricidia sepium* have also been documented (Adejuwon and Adesina 1990). Mono-species, burnt, naturally regenerated tree fallows have, in contrast, been studied less (Kass and Somarriba 1999). Examples include the bean-firewood rotation with *Senna guatemalensis* in Honduras (Felber and Folletti 1988), maize (*Zea maize*) firewood with *Lippia torresii* in wet highlands in Costa Rica (Beer 1983), and the Talun-kebun systems with bamboo (*Gigantochloa* spp, *Bambusa vulgaris*), vegetables and cassava (*Manihot esculenta*) in Indonesia (Christanty et al. 1997).

A better documented example is bracatinga (*Mimosa scabrella* Benth.) in Southern Brazil. Bracatinga is a leguminous (Mimosoideae) small tree, native to Southern Brazil in the States of Paraná, Santa Catarina and Rio Grande do Sul, between 23° to 29° S and 48° to 54° W. Rainfall in its native range is well distributed, 1100 to 3500 mm yr^{-1}, altitude between 500 to 1200 m, mean temperatures between 16 to 23 °C with infrequent, short term frosts (–3 °C). The soils are almost invariably infertile, six to eight percent organic matter (0 to 20 cm), with pH values frequently below 4.0, levels of exchangeable bases below 1 cmol kg^{-1}, levels of available P below 10 mg kg^{-1}, and levels of exchangeable aluminum up to 5 cmol kg^{-1} (Rotta et al. 1981; Laurent et al. 1990; Baggio 1994; Ziller et al. 1996). Thus it is not uncommon to find bracatinga growing on soils with aluminum saturation above 80%. Most of the soils are classified as Humic Ferrasols (Humox) or Humic Cambisols (Haplubrepts or Humitropepts) (FAO-UNESCO 1971; FitzPatrick 1980; EMBRAPA 1988).

Bracatinga is a fast-growing, heliophytic pioneer, with a lifespan of 15 to 20 years, used for firewood, charcoal, pulpwood and round-wood (Rotta et al. 1981; Baggio et al. 1986; EMBRAPA 1988). It has been used in Mexico and Central America as coffee shade (Picado 1985; Musalem 1995), and has been tested experimentaly for frost protection in coffee plantations in Southern Brazil (Caramori et al. 1996). Naturally regenerated bracatinga stands (< 10 ha in size) are found in small (< 20 ha) to medium sized (21 to 50 ha) farms in Southern Brazil. After harvesting bracatinga for firewood, debris are burnt and the land planted to a one cycle maize-bean intercrop with maize at 35,000 plants ha^{-1} and beans at 120,000 plants ha^{-1} (Baggio et al., 1986). Crop yields average 1,600 kg ha^{-1} for maize and 330 kg ha^{-1} for beans (Graca et al. 1986). Burning breaks bracatinga seed dormancy resulting in > 80% germination (Dias et al. 1981). Bracatinga seedlings are thinned when weeding the crops, yet stocking may range between 16,000 to 32,000 saplings ha^{-1} after crop harvest. The new tree stand is left unmanaged for six to eight years before the firewood is harvested and the cycle repeated. This production system, which covers some 60,000 ha in 3,000 small farms, has been practiced for nearly 100 years (Baggio and Carpanezzi 1997b, 1998).

An estimation of above-ground biomass and nutrient accumulation was made using literature data on stand age, population numbers, tree sizes, tree biomass partitioning and the concentration of major nutrients in tree tissues. A simple simulation model was used to quantify above-ground nutrient pathways and their temporal dynamics.

Data and procedures

Changes in population numbers, tree dbh and h have been documented in naturally regenerated stands of different ages (Carvalho 1981; Campos et al. 1986). Typically, stands contain 16,000 plants ha^{-1} at the end of the first year. Intensive self-thinning occurs in years four to six, followed by a slower rate of density dependent mortality which brings population size down to 825 plants ha^{-1} at year ten (Table 1). Other studies have reported between 1,800 to 2,700 trees ha^{-1} at year eight (Baggio et al. 1986) and between 1,556 to 2,867 trees ha^{-1} at year seven (Baggio and Carpanezzi 1997c). Population numbers for stands between eight to ten years age in Table 1 have been 'smoothed' by interpolation to depict the general trend. Self-thinning does occur in bracatinga stands ($\ln(w) = 17.017 - 1.834 \ln(n)$; $P < 0.0001$; $R^2 = 0.9878$; w = kg $tree^{-1}$, n = trees ha^{-1}; calculated from data in Table 1) albeit with a slope steeper than the expected –3/2 (Weller 1985).

Biomass allometric equations were calculated from data presented by Soares and Hosokawa (1984) based on destructive measurements of 72 trees, with dbh ranging between 2–20 cm:

$$\ln(\text{total}) = -2.18153 + 2.43517 \times \ln(dbh) \qquad R^2 = 0.98$$

$$\ln(\text{stem}) = -3.82473 + 1.78211 \times \ln(dbh) + 1.13488 \times \ln(h) \qquad R^2 = 0.96$$

Table 1. Number of living trees (*N*), average stem diameter at breast height (*dbh*) and total tree height (*h*) of naturally regenerated bracatinga (*Mimosa scabrella*) stands in Southern Brazil.[a]

Age (years)	*N* (trees ha^{-1})	*dbh* (cm)	*h* (m)
1	16200	1.9	4.5
2	14800	1.8	4.0
3	10100	2.5	4.3
4	7500	4.1	7.6
5	2350	8.4	12.1
6	1200	12.5	13.2
7	1075	14.2	13.9
8	975	15.6	14.6
9	900	15.7	15.3
10	825	15.8	16.1

[a] Adapted, with modifications, from Campos et al. (1986).

$$\ln(\text{branch}) = -2.24032 + 3.92232 \times \ln(dbh) - 2.07929 \times \ln(h) \qquad R^2 = 0.89$$

$$\ln(\text{foliage}) = -4.55996 + 2.26023 \times \ln(dbh) \qquad R^2 = 0.80$$

where *dbh* = stem diameter at breast height (cm); *h* = total tree height (m); and the total or compartment biomass values are oven-dry (kg tree^{-1}).

Allometric equations and inventory data were used to calculate biomass budgets at the age of one to ten years; nutrient budgets (N, P, K, Ca and Mg) were calculated using literature values for the concentrations of major nutrients in bracatinga (Baggio and Carpanezzi 1997a), maize (Sanchez 1976) and bean (Russell and Russell 1973) grain (Table 2). The number of self-thinned trees was calculated from the difference between population numbers at successive ages; biomass of dead trees was calculated using *dbh* and *h* from the preceding year (if the *dbh* and *h* of survivors in the current year were used, dead biomass would be overestimated). Foliage biomass included leaves and twigs (maximum diameter 7 mm), branch biomass refers to branches between > 7–25 mm diameter and stems refers to trunks and branches > 25 mm in diameter. Total tree biomass was calculated by summation (stems + branches + foliage) to ensure consistency in the data.

Biomass and nutrient fluxes were evaluated at year six, the most commonly practiced fallow length. At this time, trees are cut down, stems removed as firewood, and branches, foliage and dead trees left on the ground for burning to clear the site to facilitate crop planting and regeneration of bracatinga. Nutrients are exported in both stems and grains (maize and beans). The model does not include estimates for biomass or nutrients in maize and bean residues. No literature data was available on nutrient concentrations in dead trees; nutrient concentrations for live stems were used to estimate nutrient fluxes from dead trees. When comparing model results with literature data, volumes were converted to biomass using a wood specific gravity of 0.537 g cm^{-3} (Pereira and Lavoranti 1986).

Results

Total biomass is estimated as 83 Mg ha^{-1} at year six. Living stems (53%) and dead trees (28%) dominate the biomass budgets of the system. Foliage (5%) and branches (14%) are of less importance (Table 3). Firewood harvest results in important nutrient losses. Grain (maize and beans) exports amount to only between 4–16% of total losses of N, K, Ca and Mg (Table 4). However, P losses in grains represent 62% of total losses. Total estimated losses to the system (firewood + grains) amount to 274, 13, 176, 78 and 29 kg ha^{-1} of N, P, K, Ca and Mg, respectively. Branches, foliage and dead trees left on the ground amount to 356, 10, 167, 81 and 36 kg ha^{-1} of N, P, K, Ca and Mg, respectively.

Table 2. Nutrient concentrations in bracatinga (*Mimosa scabrella*) – crop systems in Southern Brazil.

Plant part	N	P	K	Ca	Mg	Source
	(% dry matter)					
Stems	0.523	0.012	0.353	0.171	0.059	Baggio and Carpanezzi 1997a
Stems	1.9	0.11	0.76	0.72	0.26	Simoes et al. 1978
Branches	1.027	0.017	0.457	0.248	0.130	Baggio and Carpanezzi 1997a
Foliage	2.949	0.134	0.788	0.293	0.167	Baggio and Carpanezzi 1997a
Foliage	2.9	0.13	0.64	0.73	0.23	Picado et al. 1985
Litter	1.912	0.117	0.097	1.197	0.257	Ziller et al. 1996
Litterfall	2.001	0.073	0.104	1.082	0.208	EMBRAPA 1988
Litterfall	2.3	0.09	0.35	0.78	0.16	Poggiani et al. 1982
Maize[a]	1.0	0.125	0.25	0.025	0.031	Sanchez 1976
Beans[a]	8.2	1.8	4.8	0.91	0.60	Russell and Russell 1973

[a] Grain.

Table 3. Estimated tree dry matter allocation at different stand ages for bracatinga (*Mimosa scabrella*) in Southern Brazil.

Age (years)	Stems	Branches	Foliage	Dead[a]	Total
	(kg ha^{-1})				
1	6,117	937	723	0	7,777
2	4,440	885	585	754	6,664
3	5,907	1,884	838	2,220	10,849
4	20,215	2,980	1,904	2,733	27,832
5	38,549	5,916	3,018	18,056	65,539
6	44,122	11,986	3,785	23,123	83,016
7	52,606	15,901	4,524	6,617	79,648
8	59,652	18,829	5,074	7,221	90,776
9	58,734	16,168	4,752	6,809	86,463
10	57,695	13,667	4,419	6,916	82,697

[a] Self-thinned trees.

Table 4. Estimated nutrient fluxes during year six for bracatinga (*Mimosa scabrella*) stands in Southern Brazil.

Component	Nutrients returned to the soil				
	N	P	K	Ca	Mg
	(kg ha^{-1})				
Foliage	112	5	30	11	6
Dead[a]	121	3	82	40	14
Branches	123	2	55	30	16
Total	356	10	167	81	36
Product	Nutrient losses due to firewood and grain harvests				
Firewood	231	5	156	75	26
Maize	16	2	4	0.4	0.5
Beans	27	6	16	3	2
Total	274	13	176	78.4	28.5
Balance	+82	–3	–9	+2.6	+7.5

[a] Self-thinned trees.

Discussion

The model predicts 83 Mg ha^{-1} of total biomass and 44 Mg ha^{-1} of firewood at year six which are comparable to the 59 Mg ha^{-1} of firewood at year seven cited by Barembuem (1988), 58 to 81 Mg ha^{-1} of total biomass at year seven reported by Baggio and Carpanezzi (1997c) and 52 to 60 Mg ha^{-1} reported for plantations and natural stands > 4 years old (Ahrens 1981; Carvalho 1981; Campos et al. 1986). Foliage biomass is also comparable to the 4.5–8.0 Mg ha^{-1} yr^{-1} of litter-fall (assuming that all foliage and twigs are shed annually) reported in the literature (Chiaranda et al. 1983; Picado 1985; Poggiani et al. 1987; EMBRAPA 1988). Total, branch and foliage biomass per tree predicted by our model are very similar to those of Baggio et al. (1995). According to our model, biomass returned to the soil at year six amounts to 38.9 Mg ha^{-1}. In a recent study, Baggio and Carpanezzi (1995) estimated a total of 40.8 Mg ha^{-1} of dry residues inmediately after firewood harvest. Biomass from understorey vegetation and un-collected firewood included in their estimate may explain the difference with predictions in this study.

Roughly half the total amount of nutrients in the above-ground biomass are exported in firewood and crops at year six. These figures are comparable to the 493, 18, 150, 116 and 68 kg ha^{-1} reported by Baggio and Carpanezzi (1997b) for N, P, K, Ca and Mg, respectively. Differences may be due to the inclusion of understory vegetation and some soil litter in the estimations of the latter authors. Large nutrient losses when biomass is burnt are also expected. A study in which bracatinga had been growing for several years at four different sites showed considerable variation in nutrient levels, but these seemed to be due to differences in parent material rather than the effect of bracatinga (Ziller et al. 1996). Tree growth and nutrient content of the litter was greater at the more fertile sites although total accumulation of fallen leaves was somewhat less variable among sites. Still, one would have to conclude that bracatinga will grow less and recycle fewer nutrients on poorer soils than on soils with high base contents. Although all soils in the Ziller et al. (1996) study were relatively low in P, litter had higher P contents and contained greater amounts of P per hectare where base content of the soil was higher. On the other hand, soil K levels did not differ greatly among sites and accumulation of K in the litter did not show a consistent difference among sites. However, levels of K in the litter were extremely low, indicating that large amounts of K might have been leached at all sites (Ziller et al. 1996). Studies in which all inputs and outputs of nutrients are consistently measured are necessary before more definite conclusions about nutrient cycling by bracatinga can be made.

Early studies claimed that neither firewood nor crop production decline after two to three fallow-harvest cycles (Baggio et al. 1986), a position later questioned by Carpanezzi (1994). Unfortunately, data gaps in the literature preclude a full analysis of nutrient balances in bracatinga fallows. No information is available on: 1) below-ground biomass and nutrient dynamics; 2) build-up of litter and soil nutrient reserves during the fallow phase (Baggio and Carpanezzi (1995) and Ziller et al. (1996) report 7.0 to 17.5 Mg ha^{-1} in six to seven year old bracatinga stands but no information is available at earlier stand ages); 3) nutrient contents in dead trees (an important biomass pathway in the system); 4) nutrient losses during and after burning forest residues; and 5) atmospheric nutrient inputs, including N fixation. Bracatinga nodulates profusely, but no data is available on atmospheric N fixation (Simoes et al. 1978).

The optimal economic rotation has been estimated at six to eight years (Baggio et al. 1986; Campos et al. 1986) which agrees with current practice by Brazilian farmers. Self-thinning in years five and six return the largest quantities of biomass and nutrients to the soil during the studied period (one to ten years). Drastic changes in population numbers in year five also facilitates crown development in year six when firewood is harvested, resulting in 12 Mg ha^{-1} of branch biomass returned to the soil. Branch biomass represents 12% of live tree biomass in year five and 20% in year six; roughly a twofold increase in one year.

Woody, monospecies, burnt fallows, linked to firewood and annual crop production like that of bracatinga, have also been documented in Central America. For example, another legume, frijolillo (*Senna guatemalensis*) forms almost pure stands in small farms in highland areas in Honduras at elevations between 1600 to 2200 m, 15 to 19 °C of mean annual temperature and rainfall of > 2000 mm yr^{-1} (Felber and Folletti 1988; Folletti 1991). Frijolillo stands are left unmanaged for eight to ten years, then all the firewood and posts are harvested, the area is slashed and burned, and planted to maize for three consecutive years (average maize yields of 584, 379 and 113 kg ha^{-1} yr^{-1}). Frijolillo seeds germinate profusely after burning crop residues and fallow debris. Self-thinning is also a typical feature of this system, but has not been documented. Four year old frijolillo stands may contain 10,000 stems ha^{-1}, with 3,800 stems ha^{-1} at year five, and 2,500 stems ha^{-1} at year eight (Felber and Folletti 1988; Folletti 1991).

Carbón (*Acacia pennatula* mistakenly reported as *Mimosa tenuiflora*) is another strikingly similar example. Naturally regenerated carbón stands are found in Honduras up to 1200 m in elevation, 600 to 1500 mm yr^{-1} of rainfall and dry period of up to eight months (Kass et al. 1993; Kass and Somarriba 1999). Fallows generally last 12 to 15 years, but they may be reduced to four to seven years when land is scarce. During the fallow period, carbón is used for fuelwood, fenceposts, charcoal production and cattle grazing under the trees during the dry season. Maize and sorghum (*Sorgum bicolor*) are cropped after the firewood harvest (Kass et al. 1993).

Another example, caragre (*Lippia torresii*, Verbenaceae) was reported by Beer (1983) to form dense, almost pure stands in humid (> 3000 mm yr^{-1}) farms at elevation 1200 m near Turrialba, Costa Rica. The stand develops after a one year cycle of maize production. After five to seven years the caragre is harvested for firewood and leaves and branches are left as mulch (burning only in dry years, personal observations) for the subsequent crop. The tree stands recover rapidly by sprouting from the stumps as well as from seed germination.

Bracatinga, carbón, frijolillo and caragre crop-fallow systems all share common traits. Almost pure, dense, self-thinning stands are formed by natural regeneration (seed and/or sprouts); multiple production objectives (firewood and crops), and not just soil fertility improvement, make the systems attractive to farmers; tree seed germination is enhanced after burning stand debris prior to crop planting; and, with the exception of caragre, they are leguminous species with similar seed characteristics. From an agroforestry perspective, the traditional bracatinga system is an improved fallow with a long (1:12) crop to fallow length ratio.

Conclusions

Available data on naturally regenerated bracatinga fallows permits a preliminary evaluation of the biomass and nutrient dynamics in this system. However, more research is needed to quantify atmospheric N fixation, below-ground dynamics and nutrient fluxes in self-thinning stands. Density dependent mortality is a major biomass pathway in the system, but its contribution to the build-up of soil reserves has received no attention in the scientific literature in this or any other self-thinning population.

Profuse seed production or coppicing ability (i.e., easy and fast tree stand regeneration), diversified production objectives (firewood, poles and annual crop production; not just soil fertility improvement) and compatible fallow and crop management activities (e.g., burning to improve nutrient availability for crops and enhanced tree seed germination) contribute to the success of the system. Several strikingly similar systems in Tropical America are based on similar traits. A comprehensive analysis of the ecological and socioeconomic characteristics of these systems is required.

Acknowledgements

This research was funded by CATIE. John Beer, Andrea Schlonvoigt, Amilton J. Baggio and two annonymous reviewers provided valuable comments on the manuscript.

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