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Taro production, phytomass input by *Sesbania* and *Flemingia* and improvement in soil fertility in agroforestry systems in floodplains

Produção de taro, aporte de fitomassa de Sesbania e Flemingia e melhoria na fertilidade do solo em sistemas agroflorestais em planície inundável

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A B S T R A C T

Floodplains were the first deforested areas for agriculture use all over the world. In Brazil these areas can be restored by the growth of guanandi *Calophyllum brasiliense*, a slow-growing native forest species adapted to flooding. The aims of this study were to: (i) evaluate the taro, *Colocasia esculenta,* management under two agroforestry systems (AFS) (Simple and Biodiverse) in succession to a reforestation with guanandi, (ii) evaluate the contribution of macronutrients from the green manure *Flemingia macrophylla* and *Sesbania virgata,* both managed using pruning for green manure in the respective AFSs, and (iii) the effects on soil nutrients levels compared to monoculture of guanandi (control). The randomized block was designed with eight replication and 216.0 m² plots with four rows of six guanandi trees in each line. In the simple AFS (SAFS), the taro was intercropped with *Flemingia* and in the biodiverse AFS (BAFS), *Sesbania*, banana shrub (*Musa* sp.), edible palm (*Euterpe edulis*) and fourteen species of native trees were included. Production was evaluated in seasons with high rainfall and water scarcity. With floods the taro has produced around 15 Mg ha^{-1} of marketable corms in the SAFS and 9 Mg ha^{-1} in the BAFS, but the drought has made commercial production unfeasible, with no differences between cormels and corms planting. However, enough rhizomes were harvested for a new planting. *Flemingia* has accumulated 17 Mg ha^{-1} of fresh matter and *Sesbania* contributed with 2 Mg ha^{-1}. Soil pH and macronutrient content, especially K, were significantly higher in AFSs areas compared to guanandi monoculture.

Palavras-chave:
Calophyllum brasiliense
Adubo verde
Fertilidade do solo
Recursos hídricos
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R E S U M O

As planícies de inundação foram as primeiras áreas desmatadas para uso agrícola no mundo todo. No Brasil essas áreas podem ser restauradas com o cultivo de guanandi *Calophyllum brasiliense*, espécie florestal nativa de lento crescimento adaptada ao alagamento. Os objetivos deste estudo foram: (i) avaliar o manejo do taro *Colocasia esculenta* na diversificação da monocultura de guanandi em dois sistemas agroflorestais (SAFs), (ii) avaliar a contribuição de macronutrientes dos adubos verdes *Flemingia macrophylla* e *Sesbania virgata*, ambas manejadas com podas para a adubação verde e (iii) os efeitos nos teores de nutrientes no solo comparados ao monocultivo de guanandi como controle. O experimento em blocos ao acaso contou com oito repetições e parcelas de 216,0 m² com quatro linhas de seis árvores de guanandi em cada linha. No SAF simples (SAFS), o taro foi consorciado com *Flemingia* e no SAF biodiverso (BAFS), com *Sesbania*, banana (*Musa* sp.), palmeira juçara (*Euterpe edulis*) e 14 espécies de árvores nativas. A produção foi avaliada em períodos com alta pluviosidade e escassez hídrica. Com inundações o taro produziu 15 Mg ha^{-1} de rizomas comerciais no SAFS e 9 Mg ha^{-1} no BAFS, mas a seca inviabilizou a produção comercial, sem diferenças entre o plantio de rizoma central e rizoma filho. No entanto, foram colhidos rizomas suficientes para novo plantio. *Flemingia* acumulou 17 Mg ha^{-1} de matéria fresca e *Sesbania* contribuiu com 2 Mg ha^{-1}. O pH do solo e os teores de macronutrientes, especialmente de K, foram significativamente maiores nos SAF comparado à monocultura de guanandi.

INTRODUCTION

Agroecology applies ecological concepts and principles for designing and managing sustainable agroecosystems (GLIESSMAN, 2018). It also focuses on reducing the dependence on external inputs (MICCOLIS et al., 2019) and promoting biological balance and resilience (ALTIERI et al., 2015). Other benefits, such as food system transformation (GLIESSMAN, 2018), are also conspicuous.

Agroforestry systems (AFSs) are the most sustainable way of producing healthy food (KERR et al., 2021). It may also promote restoration of degraded landscapes, being an option for the environmental regularization of consolidated rural land with farmer's participation (MICCOLIS et al., 2019). As these systems use shrub and tree species, frequent pruning to keep the soil covered adds organic matter and recycles nutrients that sustain intercropped species yields (GLIESSMAN, 2018; MICCOLIS et al., 2019; KERR et al., 2021).

All around the world, floodplains were the first areas cleared for agricultural use (MITCHELL, 2012; VALLEJO et al., 2015). There are indications that the region of Paraíba Valley in Southeast was the first agricultural frontier in Brazil at the coffee in the 18th century. The most suitable land for coffee farming was between 300 and 600 meters in altitude, which may be rapidly lost for erosion, especially in hilly relief, and for grain crops were on lowlands or poorly drained soil plains, which seemed to be more productive on “mud” clay soil land (BRASIL; OLIVEIRA, 2020).

Agroforestry systems may regenerate soils and water functions in these environments and produce income associating agricultural crops, shrub, and tree species tolerant to flooding on lowlands (VALLEJO et al., 2015; DEVIDE et al., 2019; KERR et al., 2021). These species have developed morphological, anatomical, and physiological changes to adapt themselves to the fast reduction of oxygen availability to the roots in lowlands and flooded areas (OLIVEIRA; JOLY, 2010).

Guanandi (*Calophyllum brasiliense* Cambess, Calophyllaceae) is a multipurpose native species to the Americas, adapted to flooding and, for this reason, a first option for riparian forests restoration (OLIVEIRA; JOLY, 2010) but also promising in commercial plantations in intensive forestry models in areas with low risk of frost and water balance, which occurs in a large part of Brazil, mainly in the Amazon region and on the Brazilian coast, due to its noble wood that replaces mahogany and cedar (WREGE et al., 2017). Despite a costly slow growth, guanandi plants may be associated with food crops in the AFSs to reduce maintenance costs, providing extra income for farmers and ecosystem services provision in the long term (DEVIDE et al., 2019; SCHWEIZER; BRANCALION, 2020).

Taro (*Colocasia esculenta* (L.) Schott) is a major horticultural species from the Araceae family's (OLIVEIRA et al., 2011; MANNER; TAYLOR, 2011) and ubiquitous crop in tropical agriculture. Taro is the staple food for many people, being a rich source of starch in the extensive plant rhizomes production (HERÉDIA ZÁRATE et al., 2009). Other favorable characteristics are a long life cycle, adaptation concerning adverse environmental and biological factors, low demand for labor (HERÉDIA ZÁRATE et al., 2009), and shade tolerance (GONDIM et al., 2007, 2018; OLIVEIRA et al., 2011; SANOU et al., 2011).

Promoting ecological restoration of flooded areas with AFS requires the use of flood-tolerant N-fixing Fabaceae as green manures. *Flemingia macrophylla* (Willd.) Kuntze ex Merr., is a multi-stem perennial shrub from Asia with medium tolerance to flooding and high tolerance to shading, used in AFSs, such as hedge (SALMI et al., 2013). *Sesbania virgata* (Cav.) Pers. (Fabaceae, subgenus Daubentonia) is a pioneer tree native to the Americas adapted to flooding and recommended for soil regeneration (COUTINHO et al., 2006).

Taro cultivation in agroforestry systems in these flooded areas can generate income. However, it is still unknown the best way to propagate plants vegetatively without rhizomes, the main commercial product (PUIATTI et al., 2003). Also, research is needed to verify the performance in different timings and models of AFSs, in addition to selection of shrub and tree species that promote fast covering of the area and provide enough essential macronutrients for taro, such as nitrogen and potassium, required in large quantities (OLIVEIRA et al., 2008) are knowledge gaps.

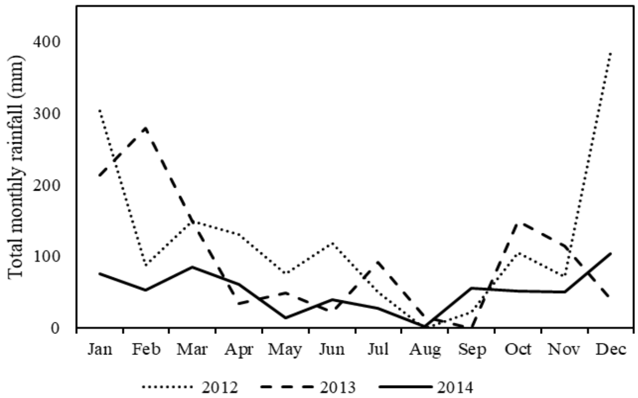
This research aimed to evaluate taro production in two AFS in the floodplain, for two consecutive years, regarding ways of planting taro, species management for green manure and effects on soil fertility. We expected that taro yield and that nutrient concentration in green manure would be higher in simple AFS than in biodiverse AFS and soil fertility would be higher in the biodiverse system.

MATERIALS AND METHODS

Study site

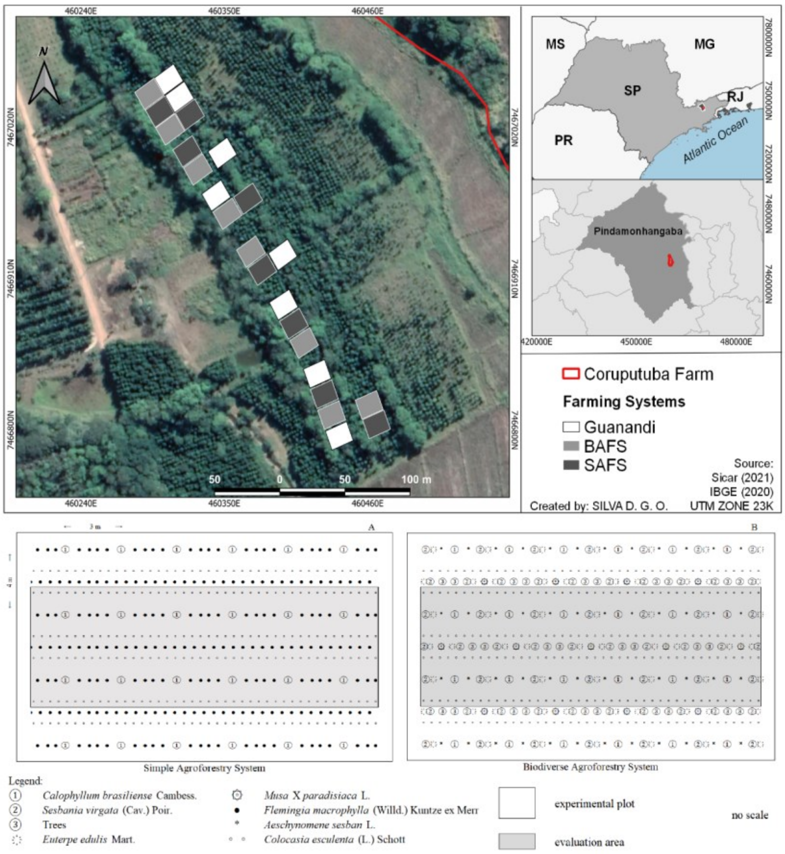
The experimental area (22º53’S and 45º23’W) is located on a traditional century-old farm (Coruputuba), which cultivates rice on the flood plain and forest species on river banks terraces, in Pindamonhangaba (SP), Paraíba do Sul river valley, Brazil, 538 m above sea level. This region of Paraíba Valley, which connects Rio de Janeiro and São Paulo states, has extensive systematic alluvial plains for agriculture. The region is under humid subtropical climate (Cwa) following Köppen classification, with warm and humid summer and temperatures over 22.0 ºC and dry winter with temperatures under 18.0 ºC. The average annual rainfall is 1200 mm. The study was carried out in a period of two years (2012–2014), annual rainfall in 2012, 2013, and 2014 was 1497, 1158, and 619 mm, respectively, with the wet season between September and March (Figure 1).

Figure 1. Rainfall between the years 2012 to 2014 in Pindamonhangaba (SP), in the Paraíba Valley, Brazil



Source: CIIAGRO, 2015.

Figure 2. Distribution of treatments in randomized blocks and representations of experimental plots, in Coruputuba farm, in Pindamonhangaba (SP), in the Paraíba Valley, Brazil.



Source: Silva (2021).

Four soil classes were classified by Santos et al. (2013), as Planosol (Planossolo), Argisol (Argissolo), Cambisol (Cambissolo), and Gleisol (Gleissolo), with sandy to clayey texture and heterogeneous sediments with physical properties modified by paddy rice since 1950. Soil chemical characteristics (Donagema et al. (2011) were: pH (water)= 4.9; H+Al= 5.3 $cmol_c\ dm^{-3}$; P= 13.8 $mg\ kg^{-1}$; K=0.12 $cmol_c\ dm^{-3}$; Ca=0.8 $cmol_c\ dm^{-3}$; Mg=0.4 $cmol_c\ dm^{-3}$ and organic matter =2.9 $g\ kg^{-1}$, proportions of clay, sand and silt ($g\ kg^{-1}$), 278, 553 and 170 respectively, and density of 2,78 $Mg\ m^{-3}$.

Experimental design

Participatory methods, recommended by agroecologists (GLIESSMAN, 2018; MICCOLIS et al., 2019), were followed and involved the Coruputubas's farmer in planning, species choice, and AFS managing in order to promote the restoration of soils, reduce the infestation of invasive plants, and produce food. A monoculture of guanandi for wood production was set at 4.0 x 3.0 m in an alluvial plain in remaining trays of rice in 2007. In Jul/2011, the agroforestry conversion research was started planting associated species in two agroforestry systems: simple and biodiverse in a randomized block design with eight replications (Figure 2) and 216.0 m² plots of four rows with six trees of guanandi in each row (Table 1).

Guanandi was intercropped with annual crops (Figure 2), while biodiverse AFS was enriched with banana (*Musa* sp.) and Brazilian native trees focused on wood, non-wood products and ecosystem services provision. Ten forest pioneer species were used: anjico preto - *Anadenanthera colubrina* (Vell.) Brenan, eritrina (*Erythrina verna* Vell), guapuruvú (*Schizolobium parahyba* (Vell.) Blake), ingá (*Inga vera* Willd.), sesbânia (*Sesbania virgata* (Cav.) Pers.), urucum (*Bixa orellana* L.), sangra d'água (*Croton floribundus* Spreng), pau viola (*Citharexylum myrianthum* Cham.), boleiro (*Joannesia princeps* Vell.) e aroeira (*Schinus terebinthifolius* Raddi.); and six non-pioneers: juçara (*Euterpe edulis* Mart.), paineira (*Ceiba speciosa* (A. St.-Hil.) Ravenna), imbirussú (*Pseudobombax grandiflorum* (Cav.) A.Robyns), ipê-rosa (*Handroanthus impetiginosus* (Mart. ex DC.) Mattos), ipê amarelo do brejo (*Handroanthus umbellatus* (Sond.) Mattos) e magnólia (*Magnolia ovata* (A.St.-Hil.) Spreng). Trees were spaced 1.5 m apart and alternated with *Sesbania* and juçara, which were also planted in lines between guanandi trees and interspaced with native paquinha shrub (*Aeschynomene* sp.). Species names follow the Flora of Brazil nomenclature pattern (http://floradobrasil.jbrj.gov.br/2012/).

Taro

Rhizomes of 'Japanese' taro, with cream pulp, rich in macronutrient minerals and green leaf plants and sheath, were planted in Sep/2012 in double rows alongside guanandi rows in a 1.0 x 0.45 m spacing (11,111 plants ha^{-1}) which represents around 33% of plant density in commercial monoculture (Figure 2); corms with an average weight of 98 g $unit^{-1}$ were used. In the 2013-2014 seasons, the effect of taro planting with corm or cormels was evaluated in split plots in fixed rows. Fertilization alongside rows consisted of organic compost (8 $Mg\ ha^{-1}$ f.w.); bone meal (1.0 $Mg\ ha^{-1}$), castor bean cake (1.0 $Mg\ ha^{-1}$), and cover with sulfate of potassium (77 $kg\ ha^{-1}$) up to 45 days after planting. Management practices were similar, excluding fertilization with castor bean cake because of the plants' vigor and residues contribution obtained from legume trees in the second year. Determinations consisted of: Plant density and Number of harvested plants (plants ha^{-1}), Plant height (cm), Number of leafs, sprouts and corm $plant^{-1}$, Fresh shoot weight ($Mg\ ha^{-1}$), Yield of cormel and corm (fresh weight) ($Mg\ ha^{-1}$). The percentage of supply of nutrient demand for the respective AFS production was determined according to Oliveira et al. (2011).

Table 1. Characteristics of guanandi trees at the time of agroforestry conversion, in Pindamonhangaba (SP) in the Paraíba Valley, Brazil

	Height (m)	Shaft height (m)	Trunk DBH*	DGL	Crown diameter (cm)
Mean ±SE	3.13 ±0.43	2.00 ±0.27	3.33 ±0.87	7.10 ±1.06	79.95 ±17.89
Max	4.50	2.70	8.69	10.35	129.00
Min	2.15	1.30	1.91	4.97	43.00

* DBH- diameter at breast height, DGL- diameter at ground level, n = 120 (number of trees evaluated in the experiment).

Green manure legumes

Fabaceae species were included in the AFSs for reducing sunlight on taro and restoring soils through pruning management, supply of phytomass and nutrients cycling in the organic mulch, breaking dense soil uplayers with the root system, activate mycorrhization and biological nitrogen fixation. To reduce damage by sun to taro leaves, which occurred in the first year of cultivation in simple AFS, *Flemingia* seedlings was planted in Nov/2012 at 35 cm intervals between taro rows, and four seedlings were planted equidistant from 75 cm, between guanandi trees (Figure 2A). Seedlings were grown in 187 cell trays. Pruning was carried out in Oct/2013 and Jan/2014, with plants being lowered to 1.0 m in height and thinning, leaving four stems per plant, according to Salmi et al. (2013).

The biodiverse AFS received *Sesbania* in association with juçara palm every 3 m and were alternated with native tree seedlings and banana shrubs (Figure 2B). *Sesbania*, juçara, and paquinha (*Aeschynomene sesban* L.) were the only plant species alongside guanandi trees. *Sesbania* received pruning in Jan/2013 and Feb/2014 by cutting branches below 1.5 m in height and reducing canopy size. Phytomass production was estimated using a digital dynamometer, and the values were converted to Mg ha^{-1} according to the average survival of each species. Sub-samples were crushed, homogenized, weighed on a precision scale, and dried in an oven at 65 ºC until constant weight. Nutrient contents of *Flemingia* and *Sesbania* were estimated (SALMI et al., 2013; QUEIROZ et al., 2007).

Soil properties

Soil samples were collected in guanandi rows and between them, in monoculture, simple and biodiverse AFS, at depths of 0-5, 5-10 and 10-20 cm, with five replications in each plot, forming a composite sample in each depth and collection point. Eight repetitions of each treatment, before and after the experiment, were used for soil chemical comparisons and were analyzed according to Donagema et al. (2011). The analyzes were carried out at the Soil Laboratory and Soil Genesis and Classification Laboratory, at Institute of Agronomy of Federal Rural University of Rio de Janeiro.

Base saturation (S) was calculated by adding the exchangeable Ca, Mg and K contents. The T value was calculated through the equation: T (cmol$_c$ kg^{-1}) = S + (H + Al), and the V value, obtained with the equation: V (%) = 100 (S value / T value).

Statistical analysis

The t test was used to compare variations of simple and biodiverse AFSs treatments in relation to taro production, within each year. In the second experimental year, the sub-divided plots were evaluated with Kruskal-Wallis test (P <0.05).

Nutrient export data were transformed using Box-Cox, as proposed by Hawkins and Weisberg (2017). Normality and homogeneity of variances were achieved and data from simple and biodiverse AFSs treatments were compared within each year using Tukey test (P < 0.05).

Phytomass contribution of *Flemingia* was based on the descriptive analysis for mean and standard deviation to Dry mass (Mg/ha) and nutrients concentration in phytomass to N, P, K, Ca and Mg (kg ha^{-1}), in simple and biodiverse AFSs. Soil fertility at depths of 0-5, 5-10 and 10-20 cm in guanandi monoculture, in simple and biodiverse AFSs, was analyzed with the Tukey test (P <0.05).

RESULTS AND DISCUSSION

Taro's growth and yeld have ranged considerably by both years of cultivation. In the first year (Figure 3A, 3B), heavy rains from Sep/2012 to Mar/2013 caused several floods in the plain. From April on, rains were scarce until the taro harvest in June. The second cultivation cycle was carried out in an arid and high-temperature environment (Figure 4A, 4B).

Tolerance of taro to flooding (MANNER; TAYLOR, 2011) improves performance in a stormy year, but water scarcity limits production (POULIOT et al., 2012), despite the good initial vegetative development in the year 2013 (Figure 4A and 4B). Water and heat stress overcame the last extreme event that peaked in 2003, and it is considered the warmest and driest period of the last 80 years in the Paraíba Valley. Weather forecasts of a 75% increase in extreme weather events and up to 40% of devastating storms (FISCHER; KNUTTI, 2015) highlight a need for actions that strengthen production for global and local food and water security. After extreme weather events, agricultural performance and resilience seem to be linked to high biodiversity level in production systems. Due to a more complex structure than monocultures, AFSs can reinforce farmers' strategies for adapting to climate change (ALTIERI et al., 2015).

Figure 3. Taro in the first year, in 2012, in the simple AFS (A) with high luminosity in flood soils and with little sunlight in *Sesbania* understory and other species used in the biodiverse AFS (B) alongside lines of guanandi in Pindamonhangaba (SP) in the Paraíba Valley, Brazil (2012).

Source: Autors (2022)

Figure 4. Taro grown in simple AFS with high luminosity after pruning in *Flemingia* (A) and taro cultivated in low light, in biodiverse AFS (B) alongside lines of guanandi, in dry year in Pindamonhangaba (SP) in the Paraíba Valley, Brazil (2013).

Source: Autors (2022)

Crop yield, height, and leaf number

Among the two systems and within each year, the best results were obtained in the simple AFS. In the first year, this system was superior in harvested plants (P = 0.036), number of viable leaves (P = 0.0016), sprouts (P <0.0000), shoot (P = 0.015) and rhizome weight per plant (P = 0.028), resulting in higher yields of cormels (P <0.0000) and corm (P = 0.0434) (Table 2), comparing similar plant size among AFSs. The simple AFS overcame the biodiverse AFS by 64.0% and 43.0%, respectively, to produce corms and cormels. The yield of rhizomes of 0.87 kg plant^{-1} in simple AFS is satisfactory, considering that Gondim et al. (2007) recorded 1.05 kg plant^{-1} with 18.0% artificial shade. The lower production in the biodiverse AFS results from lower plant survival since taro does not compensate the production with the increase of available space due to the reduction in the planting stand (PUIATTI et al., 2003) and also for the excess of shade, which might delay rhizomes formation in 30 days (OLIVEIRA et al., 2011).

Rhizomes yeld, the number of leaves and sprouts were higher in the simple AFS, despite the similar height of the plants; different from the result of taro growing at higher shade densities of native tree species in West Africa, according to Sanou et al. (2011) and Pouliot et al. (2012). Oliveira et al. (2011) obtained greater yeld with shade levels of 25 to 50%, which are similar to conditions of simple AFS.

Weather changes in the last two years in the region affected taro yield and decreased performance in the second growing season due to drought. There were significant reductions in the number of harvested plants, plant height, number of sprouts, and corms number per plant. As a result, there was a drop in total rhizome production of 87 and 93% for simple and biodiverse AFS.

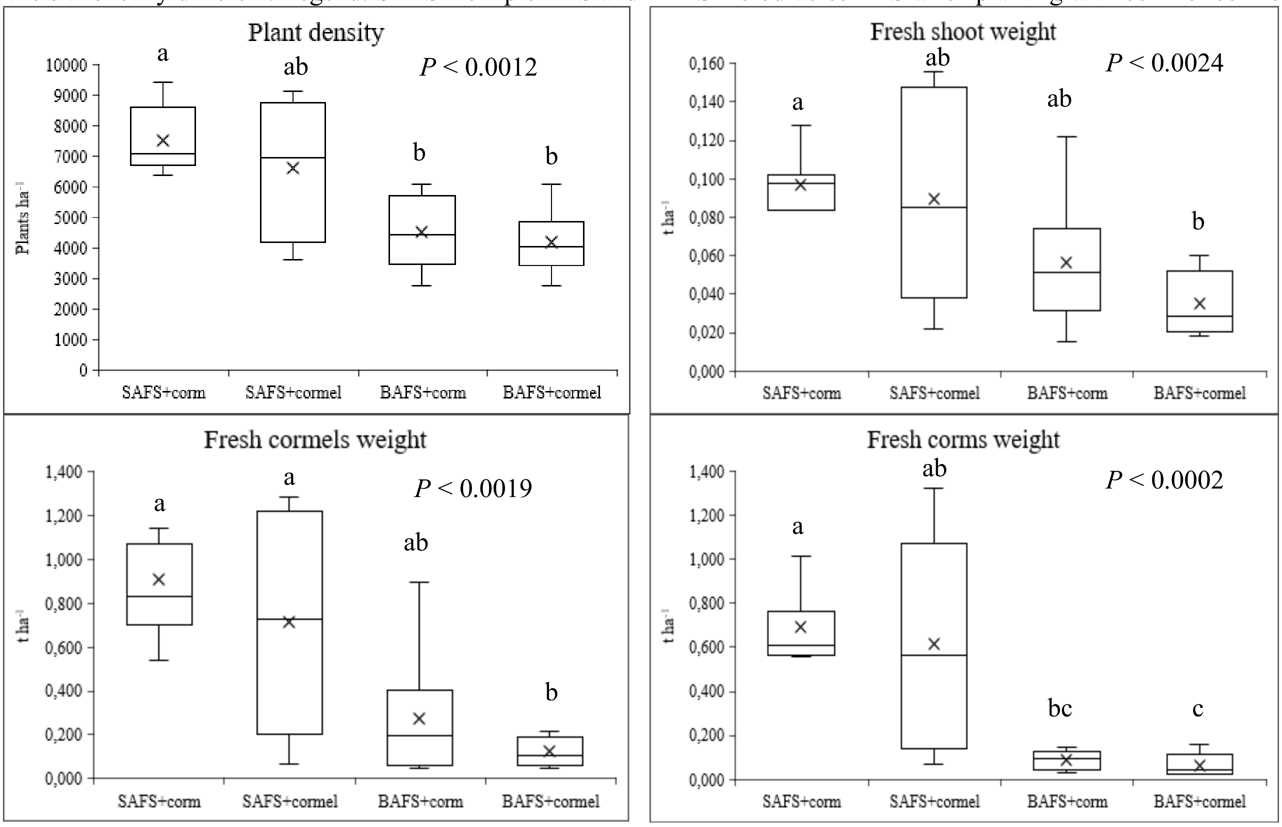
Despite water stress and higher taro performance in simple AFS, the number of sprouts per plant was similar between AFSs (P = 0.2768). In the second crop, there was no difference between planting cormel and corm within each AFS (Figure 5). However, the highest values of fresh cormels weight, fresh corms weight and fresh shoot weight were obtained in simple AFS. The number of plants harvested was decisive for best results of the simple AFS (an average of 7,066 plants ha^{-1} in planting with corm, against 4,340 plants ha^{-1} in the biodiverse AFS: Figure 5). When planting cormels, these differences have been kept but this propagating material resulted in a more significant variation in plant density at harvest in the simple AFS, producing fresh shoots weight and fresh rhizomes weight in this system.

Table 2. Number of harvested plants, plant height, leaf and sprout per plant in the harvest and fresh sprout weight, and production of corms and shoots in simple and biodiverse AFSs in Pindamonhangaba (SP), in the Paraíba Valley, Brazil

Measurement	Year	AFS Simple	AFS Biodiverse	P-valor
Number of harvested plants (plants ha^{-1})	2013	10764 a	10104 b	0.0360
	2014	7535 a	4514 b	<0.0000
Plant height (cm)	2013	94.16 a	89.63 a	0.4807
	2014	42.06 a	31.63 b	<0.0000
Leaf number plant^{-1}	2013	5.03 a	3.63 b	0.0016
	2014	5.28 a	3.91 b	0.0001
Number of sprouts plant^{-1}	2013	2.91 a	0.44 b	<0.0000
	2014	1.03 a	1.06 a	0.2768
Number of corm plant^{-1}	2013	16.85 a	12.33 b	0.0280
	2014	1.87 a	1.74 a	0.3033
Fresh shoot weight (Mg ha^{-1})	2013	1.23 a	0.78 b	0.0150
	2014	0.11 a	0.06 b	0.0065
Yield of cormel (fresh weight) (Mg ha^{-1})	2013	5.38 a	2.32b	<0.0000
	2014	0.91 a	0.27 b	0.0006
Yield of corm (fresh weight) (Mg ha^{-1})	2013	9.69 a	6.20 b	0.0434
	2014	0.89 a	0.14 b	0.0035

Different letters indicate difference in row.

Figure 5. Performance of taro based on plant density at harvest, fresh weight of shoots, cormels and corms in simple and biodiverse AFSs under water stress in Pindamonhangaba (SP) in the Paraíba Valley, Brazil. [a]different superscripts above the box plot are statistically different. Legend: SAFS – simple AFS and BAFS – biodiverse AFS when planting with corm or cormel.



The decreasing order of macronutrient absorption and exported in commercial taro rhizomes was similar in both AFSs: K> N> P> Ca> Mg (Table 3). K and N were the macronutrients exported in larger amounts. The decreasing rate of macronutrients absorption exported in corms was similar among both AFSs, but it differs from Oliveira et al. (2011) findings in soils with a higher concentration of Ca and Mg (K> Ca> N> Mg>P).

According to Oliveira et al. (2011) and Gondim et al. (2007), the restriction of light does not affect macronutrient accumulation. However, it induces a initial growth in the aerial part diminishing root growth, causing delay in corms formation (OLIVEIRA et al., 2011), and consequently reducing final production, which probably has occurred in the biodiverse AFS. In the first life phase, taro plants invested more photoassimilates in aerial part and roots, emphasizing these components for rhizomes production. The maximum accumulation of macronutrients in taro aerial part and roots that occurred for N, P, and K within 102 days and for Ca and Mg within 123 days after planting, whereas in cormels and corms occurred around 240 and 270 days, respectively, according to Oliveira et al. (2011). At the end of plant life, there was an intense translocation of photoassimilates from the aerial part to storage organs (rhizomes). Althougt taro growth in AFSs occurred in drought conditions (Figures 4A, 4B), shading avoided leaf damage by the sun (GONDIM et al., 2007), and the plants were able to store photoassimilates in the aerial part and possibly translocate them to ensure the rhizomes production that can be used in new planting. Where cormels have no market value they may also be used as propagating material (PUIATTI et al., 2003). Maximum nutrient absorption in taro leaves and rhizomes in a shaded environment occurs at different times, according to Oliveira et al. (2011). In agroforestry systems, this possibly occurred in January and May, respectively, and May/2014 was the month with the lowest rainfall.

Table 3. Export of nutrients in taro corm production in the two respective agroforestry systems in two years of harvests in Pindamonhangaba (SP) in the Paraíba Valley, Brazil

AFS	Year	Dry mass	N	P	K	Ca	Mg
		kg ha^{-1}					
Simple	2012	1620Aa	29.17Aa	8.86Aa	59.07Aa	5.17Aa	3.32Aa
Biodiverse		1436Aa	25.86Aa	7.86Aa	52.37Aa	4.58Aa	2.95Aa
Simple	2013	149Ab	2.68Ab	0.82Ab	5.43Ab	0.32Ab	0.21Ab
Biodiverse		32Bb	0.58Bb	0.18Bb	1.15Bb	0.10Bb	0.07Bb

In column, different uppercase letters indicate difference between treatments within each year and different lowercase letters indicate difference within each treatment between years.

Management of green manure legumes

In *Flemingia*, the cutting height above 1.2 m resulted in maximum accumulation of phytomass (Table 4), with K release with a half-life of 19 days in residues, accord Salmi et al. (2013). Thus, the estimated contribution of K in the simple AFS with *Flemingia* was 35.9 and 80.8 kg and with *Sesbania* 16.4 and 7.6 kg in the first and second years, respectively. Further research is needed for adjustment of pruning season according to the demand for nutrients in taro, considering half-life required for nutrients release for taro plants (SALMI et al., 2013).

Flemingia is a multi-stem species that accumulates lots of phytomass (SALMI et al., 2013). It brings stability to soil due to its high contents of protein and fiber levels, forming a mulch that keeps moisture and increases soil N and P (OPPONG et al., 1998). *Sesbania* contributed to dried phytomass supply of 1.98 Mg ha^{-1} and nutrients to biodiverse AFS, in pruning in Jan/2013 and Feb/2014, but with a decrease of 45% in the second pruning (Table 4). As showed by Queiroz et al. (2007), for the management of *Sesbania* pruning in an alley cropping, with an accumulation of 1.74 Mg ha^{-1} of dry mass in two years, and a decrease of 41% in the second year, with drought (QUEIROZ et al., 2007).

Table 4. Dry mass and concentration of nutrients in phytomass of *Flemingia*[1] and *Sesbania* [2], respectively in simple and biodiverse AFSs, in corm planting of taro, in Pindamonhangaba (SP) in the Paraíba Valley, Brazil

Species	Date of pruning	Dry mass	N	P	K	Ca	Mg
		kg ha^{-1}					
Flemingia	2013	5,271 ± 1,070	116.0 ± 23.55	11.0 ± 2.24	35.9 ± 7.29	43.5 ± 8.83	13.9 ± 2.83
	2014	11,853 ± 2,387	260.8 ± 52.53	24.8 ± 4.99	80.8 ± 16.26	97.7 ± 19.68	31.3 ± 6.30
Total		17,124a ± 2,856	376.8a ± 62.84	35.8a ± 5.97	116.7a ± 19.45	141.2 ± 23.55	45.2 ± 7.54
Sesbania	2013	1,374 ± 647	41.5 ±19.55	2.9 ± 1.37	16.4 ± 7.70	-	-
	2014	614 ± 189	18.9 ± 5.83	1.3 ± 0.40	7.6 ± 2.33	-	-
Total		1,988b ± 788	60.4b ± 23.89	4.2b ± 1.67	24.0b ± 9.43	-	-

According to [1] Salmi et al. (2013) and [2] Queiroz et al. (2007). Different letters in column indicate difference in the total values of green manure.

It is a challenge to define the most appropriate AFS models for ecological restoration. AFSs promote rapid soil coverage, but native species are not always used. *Sesbania* is a species adapted to flooding that occurs naturally in the alluvial plains of the Paraíba do Sul River, but *Flemingia* is a species native to Southeast Asia (SALMI et al., 2013) and can become invasive in riparian areas that are protected by law in Brazil. *Sesbania* is a species qualified to restore soils, because of biological nitrogen fixation, and activates mycorrhizal fungi that promote plant growth (COUTINHO et al., 2006), but phytomass contribution in pruning is limited (QUEIROZ et al., 2007). Thus, this species has improved better edaphic environment and microclimate than supplied phytomass. In the final stage of development before *Sesbania* flowering, tissues and organs start senescence. In this phase, characterized by an orderly disassembly of macromolecules, protein catabolism releases organic nitrogen and sulfur in the form of soluble amines (MÓGOR et al., 2018). The products of these pathways are small, soluble molecules that are readily exported from the senescent tissue and thus allow the plant to relocate them to other parts of the plant (MÓGOR et al., 2018), which in *Sesbania* coincided with flowering and filling of green beans. At this stage, most severe attack by defoliating beetles (in this case, Chrysomelidae - *Chalcoplacis* sp. and others) also occurs (SILESHI et al., 2000). These factors contributed to the reduction in accumulation of plant fresh matter.

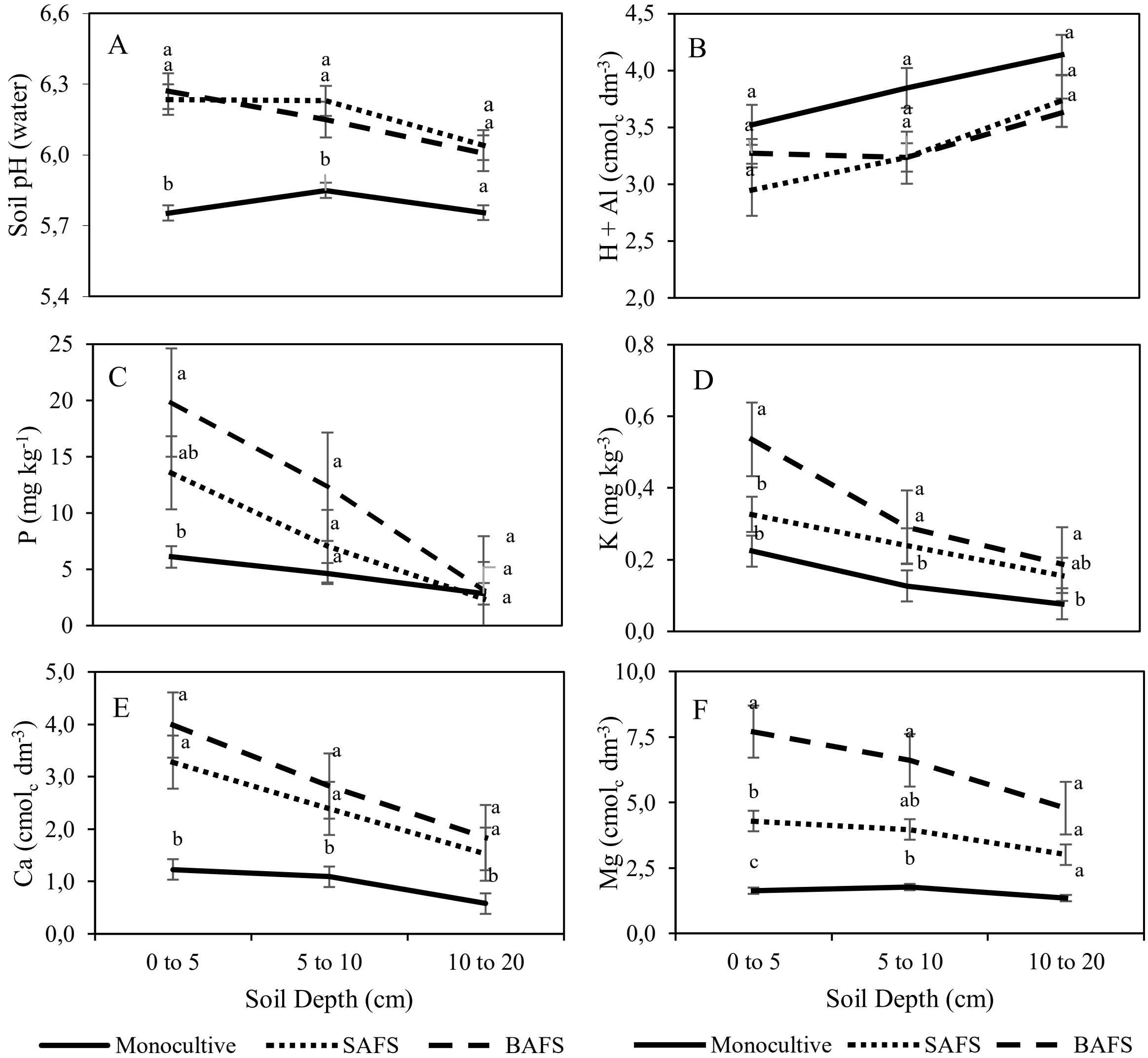
Soil chemical properties

Soil fertility has improved in all systems with a significant increase in the AFSs of soil pH and K, Ca, Mg levels, due to fertilization and Fabaceae cultivation. In the superficial layer, K and Mg contents were higher in the biodiverse AFS (Figure 6). Before the experiment, soil fertility did not show significant differences in the studied depths.

AFSs are adequate to promote restoration of floodplain areas (VALLEJO et al., 2015; BROWN et al., 2018), and the participatory research on agroforestry systems inserts farmers in ecological restoration (MICCOLIS et al., 2019). Simple AFS is as a semi-intensive production system in which the annual culture promotes food security and generates income in the short term. Biodiverse AFS is benefited by species diversity where taro was an annual component. It produces food and generates income in the initial stage, contributing to soil cover and survival of long-cycle forest species, such as the studied edible palm. An annual crop may enable introduction of other species, as arrowroot (*Maranta arundinacea* L.), which also tolerates soil flooding and has reserve structures making possible to overcome longer dry periods (DEVIDE et al., 2019). Given species diversity, it was expected that this system would result in more restrictive environmental conditions for taro cultivation.

The results of this research support new studies and bring relevant innovative information that contribute to advances in the quality of agroforestry management. It demonstrates taro potential to compose the low stratum in these agroecosystems. It presents data on pruning quality (nutrient content) of using *Flemingia* as green manure, and changes in soil fertility as a consequence of management.

Figure 6. The soil fertility at depths of 0-5, 5-10 and 10-20 cm in the monoculture of guanandi, in simple and biodiverse AFSs in Pindamonhangaba (SP) in the Paraíba Valley, Brazil. [a]Different lowercase letters indicate difference between treatments within each depth.. Legend: SAFS – simple AFS and BAFS – biodiverse AFS.



CONCLUSION

The production of taro rhizomes was higher in simple AFS, and, for this reason, it represents the intensive exploitation of taro in a floodable environment. Cormels can be used in AFS, but taro production in the dry season is sufficient only to obtain seed rhizomes for new planting.

Flemingia, in an association, provides organic residues with enough nutrients to maintain the high productivity of taro. *Sesbania* had accumulated an insufficient amount of phytomass to meet taro demands for macronutrients.

Biodiverse AFS is a system with several strata that aims to obtain product diversity over time. However, interspecific competition and the excess shading limit taro production in the driest season.

The agroforestry conversion of guanandi monoculture improved fertility of floodable soils, mainly in the superficial layer, and K and Mg contents were higher in the biodiverse AFS.

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