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The influence of different photosynthetically active radiation levels on *Ananas comosus* (var. *erectifolius* LB Smith) plants under multiple cropping systems in the upland region of the Guama River, eastern Amazonia.

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Abstract

Changes in the photosynthetically active radiation (PAR) levels to which a certain species are adapted can result in different plant growth responses. Thus, analytical and systematic studies on the mechanisms that plant species use to survive when subjected to changes in PAR are required. To address the lack of literature on this topic for *Ananas comosus*, this study aimed to evaluate the effects of different PAR levels on the growth of this species. A completely randomised experimental design was used consisting of subdivided plots containing a total of 1176 forest plants, including 1040 Sc (*Schizolobium parahyba* subsp. *amazonicum*), 96 Cg (*Cordia goeldiana* Huber), 40 Sw (*Swietenia macrophylla* King), and 13.000 *An* (*Ananas comosus* var. *erectifolius*) agricultural plant species. Seven treatments were established based on this combination of species. These treatments were installed using a completely randomised block design with split plots. Each plot measured 18 m x 24 m, and each treatment was replicated four times, resulting in a total of 28 plots and an experimental area of 12.096 m². After establishing the treatments, studies were conducted to evaluate the influence of different radiation levels on *An* plant growth. In this study, pluviometric precipitation data and mean percentage values (53, 64, 71 and 100%) of PAR (μmol m^{-2} s^{-1}) were recorded. Over the period between 2003 and 2006, the number of leaves, the lengths of the leaves, and the number of *An* sprouts were measured every six months. The highest number of leaves was recorded in the treatments in which the plants were exposed to 64% PAR. The number of leaves in this treatment was similar to that in the 71% PAR treatment. However, the number of leaves decreased in the plants that were subjected to either the highest (100%) or the lowest (53%) level of PAR. The use of different PAR levels for *An* plants under cultivation conditions showed that the best growth rates of the leaves and shoots were associated with lower levels of PAR (53% and 64%). However, cultivation under full sunlight favoured a higher number of leaves. The fibre, leaf and mucilage production progressively increased until the third year of the experiment.

Keywords: "Curauá", cultivation system, luminosity and fibre.
Abbreviations: PAR_Photosynthetically active radiation, An_*Ananas comosus*, Sc_*Schizolobium parahyba*, Cg_*Cordia goeldiana* Heber, Sw_ *Swietenia macrophylla* King.

Introduction

The arboreal components in agroforestry systems can influence the development of herbaceous species in different ways. In particular, absorption of light for photosynthesis and the growth of roots to increase the uptake of nutrients and water may be influenced. Changes in the light level to which an adapted species is exposed can result in different physiological, biochemical, anatomical and growth responses. In this way, growth efficiency is related to the ability of plants to adapt to environmental luminosity conditions (Kozlowski et al., 1991); (Atroch et al., 2001), and this capacity is an essential condition for associations of agricultural species and pasture with trees. Several vegetal species can develop under shade or high luminosity conditions because they have photosynthetic mechanisms that are better adapted to such environments. This adaptability applies to bromeliads, which acquired the ability to adapt to several different climates during evolution. Thus, according to the needs and adaptability of the Bromeliaceae family, solar radiation represents an important climate factor that can influence the full development of the plants. Among the bromeliads, *Ananas comosus* var. *erectifolius* (LB Smith) Coppus & Leal (*An*) has great economic potential. In Para state, *An* has been cultivated with forest species and has exhibited good growth in the Santarém, Bragança, Santo Antonio do Taua, Mojú, Ponta de Pedras and Vigia municipalities. Its fibre has greater lightness and strength compared with other vegetable fibres, which allows its use in several industrial applications, mainly as a reinforcing polymer that can replace partially synthetic fibres such as asbestos, Kevlar, boron, carbon, nylon and glass (Mothé and Araujo, 2004; Monteiro et al., 2006; Beltrami et al., 2014; Argazini et al., 2014). Moreover, its fibres are a renewable natural resource that is inexpensive, biodegradable, recyclable, non-toxic and can be incinerated (Araujo et al., 2003). According to Viégas et al. (2014), *An* fibre has excellent chemical properties. It can be used for paper production and is used in the automotive industry for the manufacture of car seats. *An* fibre is currently listed as a replacement for fibreglass in automobile parts and as a component of beams that are resistant to earthquakes. Thus, it appears that the species has many different uses, which makes it of great importance in the global economy. In agroforestry plantations, biological characteristics as well as economic potential must be considered when selecting species. The benefits of crop production include simple processing and the ability to grow crops in monoculture or in intercropped systems in forest areas (Lamb et al., 2009). Crop production is an important source of income and employment in most low-income regions; thus, it provides opportunities for families and small farmers (Araújo 2003; Silva et al., 2008a; Silva et al., 2008b). In northeastern Pará, Lamb et al. (2010) found that plant culture is profitable and economically feasible, and when used in forest plantations, it can help recoup the initial investment associated with the deployment and maintenance of the agroforestry system, which increases the final production of forest species and is therefore sustainable. However the information about the kind of behavior in different cropping systems are still limited in the literature. In addition to presenting a production system, a consortium of design, rules and management advice, the use of Ananas is justified by the idle space in the early years of establishment of forest species, combining the ability to earn an income with the production of leaves, seedlings and fibers with various crops, generating income and return in a short period. However, little is known regarding the environmental conditions that can influence the growth of these plants or the systems in which the plants can be cultivated. To evaluate the plant response to different degrees of luminosity, parameters such as the height, weight of dry matter, and the plant root/shoot ratio are typically measured. However, (Scalon, 2002) reported that growth characteristics should be used to determine species tolerance or intolerance to low luminosity. Studies on the evaluation of light incidence in pineapple growth areas are scarce. However, such studies are necessary to understand different light exposure conditions, such as full sun and shade. This type of work was conducted by (Keller et al., 2005) who evaluated the use of light in three species of bromeliads from full-sun and shaded sites. These authors showed that there was no photoinhibition under light conditions and that variability in the availability of light affected the activity and growth performance of wild pineapple. To address the lack of literature surrounding this topic, this study aimed to evaluate the effects of different photosynthetically active radiation (PAR) levels on the growth of cultivated *Ananas comosus* var. *erectifolius* (LB Smith) to broaden our knowledge of cultivation techniques and provide accurate information on efficient methods for cultivating these plants in Pará State, Brazil.

Results

Radiation levels and length of leaves

According to analysis of variance, at different PAR levels, *An* exhibited significant differences with respect to the numbers and lengths of the sprouts in the various plots. There was a significant time effect, and there were significant plot and subplot interactions for the two analysed variables lear numer and length (Table 1). *Ananas comosus* showed distinct patterns with respect to the analysed parameters in response to the PAR levels and the time period under study. According to the means test presented in Table 2, significant differences were noted between all of the parameters evaluated in the different treatments. Treatment differences were observed in the number of leaves. The highest number of leaves was recorded in the treatments in which the plants were exposed to 64% PAR. The number of leaves in this treatment was similar to that measured in the 71% PAR treatment. However, the number of leaves decreased when the plants were subjected to either the highest (100%) or the lowest (53%) level of PAR. The highest average leaf length was measured at the 53% PAR level, with an average length of 73.13 cm per leaf. This number was not significantly different from the average value observed in the 64% PAR treatment. The lowest PAR intensity induced the best response in terms of the number of sprouts, with a value of 67.68%, which was significantly higher than the values obtained in the other treatments. In the treatment with a PAR level of 64%, the number of sprouts was the same as that measured in the 71% PAR treatment, and this value was greater than that measured in the 100% PAR treatment. The collected data indicated that *An* presented different responses to PAR levels after the beginning of the experiment, showing variations in leaf number and length. Another visual observation was the change in the colour of the leaves, which showed a variety of green tints. The leaves of *An* plants that were associated with *Sc* presented better growth, greater strength and a green-violet colour. However, the plants cultivated in the one-year-old forest that was composed of *Sc* and *Cg* species (Jenny Wood) presented a pink-reddish colour with narrow and short leaves (Figure 3). In addition, the plants cultivated in the two-year-old forest containing *Sc*, mahogany and *Cg* presented the same colouring with narrow and short leaves (Figure 3). One year later and after the first harvest, the treatment difference gradually diminished, and the plants became stronger and showed similar leaf colours.

Magnitude of PAR

In the first year, the plants in the 53% and 71% PAR treatments exhibited heavier leaves. In the second year, a similar response was observed in the plants in the 64% and 71% PAR treatments. In the third year, plant performance returned to the standards observed in the first year.

The results show the magnitude of the PAR variations in the 36-month study period, with PAR values of up to 1725.5 μmol m^{-1} s^{-2} in 2004 for *An* exposed to full sun. We note that in 2005, the PAR decreased considerably, even under full-sun conditions, to a value of 616 (μmol m^{-2} s^{-1}). In addition, according to (Poggiani, et al., 1992), the light response curve of the leaves indicated saturation (500 and 1000 μmol m^{-2} s^{-1}), however, the maximum total amount that can be achieved is of 2000 μmol m^{-2} s^{-1}. Based on the variations in the magnitude of PAR, the value was lower than those measured in 2003 and 2004, and reached 267.4 μmol m^{-2} s^{-1} in 2005 in the *Sc*2*An*3 treatment. This condition could be related to a reduction in rainfall in 2005 (Fig. 2).

Discussion

A comparison indicated that the 53% PAR treatment caused substantially longer leaf lengths and a higher number of sprouts compared with the other treatments.

Table 1. Summary of the analysis of variance results from the completely randomised experimental design with subdivided plots and with the following variables: the lengths of the leaves (LL) and the number of leaves (NL) of *Ananas comosus* var. *erectifolius* (LB Smith) under different PAR levels.

Sources of variation	Leaf length			Number of leaves	
	DF	SQ	F	SQ	F
Treatments	3	1.336,05	0.0008**	0.1593090	0.0274*
Standard Error	12	208.78	-	0.4878662	-
Time	5	15.362,76	0.0000**	0.7184384	0.0000**
Treat*Time	15	85.71	0.0000**	0.5110914	0.0000**
Residual	60	18.27	-	0.9703411	-
Total	95	-	-	-	-
CV (%)	6,72			2,23	
Average	63,6			1,39	

Observations = 96; *Significant and **highly significant at the 5% and 1% probability level, respectively, according to the "F" test. DF = Degrees of freedom, SQ= Sum of squares.

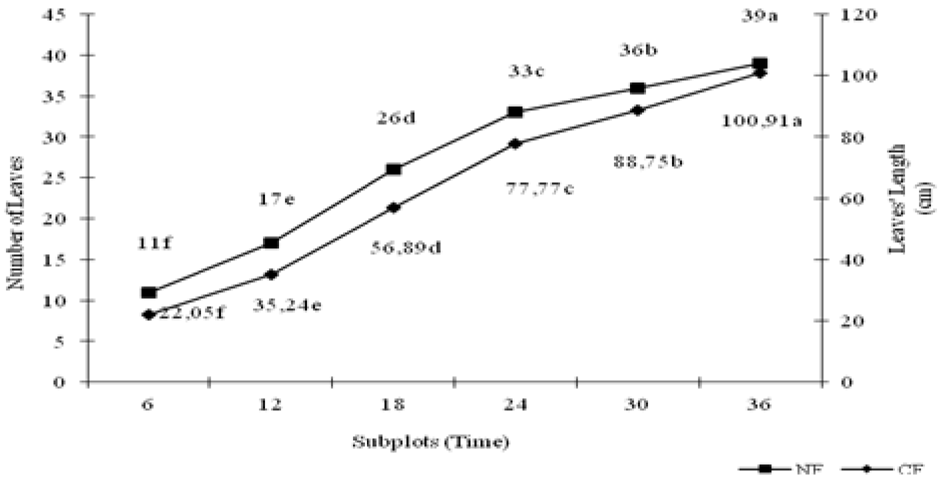

Fig 1. Average cumulative increase in the number of leaves (NF) and leaf length (CF) of *Ananas* var. *erectifolius* collected every 6 months during the 36-month study.

These numbers were much higher than those obtained for the plants under full sunlight conditions (100% PAR). *An* is a light-demanding species; however, the decrease in PAR due to tree crowns did not impair its growth, which indicates that this species can adapt to various PAR levels. In addition, the result leads to the assumption that *An* possesses characteristics of shade-tolerant species.The results showed that initial plant growth was slow. However, growth increased incrementally in all treatments during each time period, demonstrating that *An* metabolism can adapt to PAR levels during the initial stage of development (i.e., establishment), after which, the lowest levels of PAR benefit the growth of *An* leaves. The results showed that the plants exposed to intermediate levels of shade produced a higher number of leaves to ensure that a greater foliar area was exposed to light such that the plants could better execute their metabolic functions, especially photosynthesis. This hypothesis corresponds with the findings of Carvalho (1999). The average leaf length did not differ significantly between the 53% and the 64% PAR level, which indicates that rapid growth is an important mechanism of species adaptation to shady environments and is a valuable plant strategy to overcome low light conditions. These adjustments decreased the flexion of the bromeliad leaves. Bromeliads that inhabit shade environments have longer and narrower leaves with larger surface areas compared with bromeliads that inhabit sunnier locations (Carvalho et al., 1998).

Plants that grow in shade increase their foliar surface to increase their exposure to sunlight, which is essential for certain metabolic activities (such as photosynthesis and growth). However, bromeliads living in high luminosity environments present a different behaviour. Instead of increasing their foliar surface, they reduce it to avoid solar radiation and higher microhabitat temperatures that cause their leaves to over-transpire. For example, other researchers (Carvalho et al., 1998; Osunkoya et al., 1991; King, 1994) reported that plant height was greater under shade conditions, which is a response caused by cell lengthening to capture more sunlight. According to Wardlaw (1990), plants cultivated under low luminosity conditions should produce greater amounts of photoassimilates in their aerial portions. Moreover, greater cell lengthening may contribute to taller plant heights in shade environments. These results likely depend on the species and the adopted experimental management because every species requires a certain level of shade for its development. However, according to Nodarl et al. (1999), the number of leaves is not a suitable characteristic for use as a reference regarding growth differences when plants are subjected to different light levels because continuous leaf fall and production occur. In this study, which was conducted at the same experimental site, the authors reported that shade caused by *Sc* plants did not interfere with the growth of *An*. In addition, Dias-Filho (1999) reported that some vegetal species possess the ability to adapt themselves to the solar radiation conditions under which they are placed or where they are already developing because they have enhanced photosynthetic mechanisms tailored to these conditions. Furthermore, (Scalon et al., 1993) emphasised that species that behave satisfactorily in reduced-light and full-sunlight environments are suitable

Table 2. The average data from 3-year-old *Ananas comosus* var. *erectifolius* (LB Smith) plants for the following variables: the numbers of leaves, the lengths of the leaves, and the number of sprouts relative to the PAR.

PAR intensity	Plant		plot
(%)	Number of Leaves	Leaf Length (cm)	Number of Sprouts*
100	23.70 b	57.62 b	40.56 c
71	25.19 ab	57.70 b	42.78 bc
64	26.73 a	65.97 ab	46.11 b
53	23.55 b	73.13 a	67.78 a

Averages followed by the same letter within a column are not significantly different according to the SNK test (α=0,05). *Actual data; the data were log-transformed for the analysis.

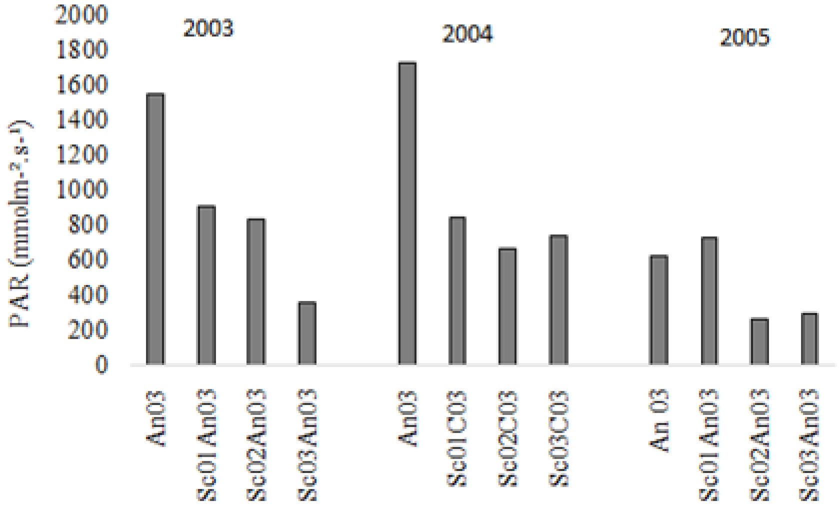

Fig 2. Annual average photosynthetically active radiation received by *Ananas* var. *erectifolius*: "single" *Ananas comosus* var. *erectifolius* (*An*) for the 2003-03 planting year (An03); Sc01 – Sc - *Schizolobium parahyba* subsp. *amazonicum* (Huber ex Duck) Barneby paricá combined with *An* planting in 2001 and 2003; Sc- *Schizolobium parahyba* subsp. *amazonicum* (Huber ex Duck) Barneby paricá combined with *An* planting in 2002 and 2003 (Sc02An03); paricá combined with *An* planting in 2003 (Sc03An03). The total study period spanned 36 months.

for intercropping systems. This fact corresponds to the results of the present study. Nevertheless, large differences in radiation intensity may have little influence on growth. In addition, the effects on the plants only become measureable when the degree of light reaches a critical limiting level for a certain species. The satisfactory adaptation of *An* to local edaphic conditions and climate, and particularly to different PAR levels caused by forest species, is likely attributed to the high saturation that is presented by this species at different PAR levels, resulting in its cultivation in different agroforestry systems. However, further studies on the physiological processes of the species in agroforestry systems are necessary to determine the maximum level of solar radiation that the plant can tolerate. Environmental factors, such as luminosity, water, temperature and edaphic conditions, may influence vegetative development. The absence or excess of these factors can reduce plant strength and impair growth. However, Kozlowski et al. (1991) reported that the cited luminosity factors are considered vital for vegetative growth because of their critical influence on light-dependent reactions, such as photosynthesis, stomatal opening and chlorophyll synthesis. Scalon et al. (1993) stressed that plant growth characteristics can be used to assess the tolerance or intolerance of a species to low luminosity. Thus, according to this study, the physiological plasticity of the species relative to the available photosynthetically active radiation can be measured by evaluating plant growth at different PAR levels. Insufficient or excess luminosity can harm bromeliads. Generally, bromeliads with insufficient luminosity have bent and soft leaves that are longer than normal (Paula, 2000). In addition, excess light causes the leaves to turn yellow or brown, dry up, or become shorter than normal, with varied degrees of light-induced damage. A study conducted on the *Neoregelia johannis* bromeliad population in the Atlantic Forest, which is located in Ilha Grande on the seashore of Rio de Janeiro State, Brazil, showed substantial differences among the individuals with respect to their size and colouring. Cordeiro et al. (2004) demonstrated a direct relationship between luminosity intensity and the colouring of the plant. Depending on the amount of light a plant receives, it can present certain colours, which are derived from pigment concentrations, as well as specific sizes and shapes. Different bromeliad genera require distinct luminosity levels for their full development. For example, according to Trotman (1990), *Aechmea* bromeliads need 500 to 1000 lux of light, whereas *Guzmania* bromeliads require luminosity levels of only 300 to 500 lux. Thus, Head (1997) stated that the optimum luminosity level is that under which the plants present neither light damage nor a loss of colour. The presence of arboreal components in agroforestry systems can have various influences on the development of the vegetal herbaceous stratum. In this case, it was demonstrated that bromeliad growth was favoured by arboreal vegetation during the study period, which allowed us to conclude that the plants often live in the same environment without any competition between them. In agroforestry systems in arid zones, the partial protection provided by trees favours the productivity of some succulent species, such as *Aloe vera* (Díaz et al., 1990) and *Agave cocui* (Díaz, 2001). This response occurs due to the protection that the trees provide to crassulacean acid metabolism (CAM) plants, favouring

Table 3. *Ananas comosus* leaves, fibre and mucilage production at different PAR levels.

Radiation Intensity (%)	Leaves	Fibre	Mucilage
	Kg/ha		
	One year after planting		
100	7.514,882	495,982	1.953,87
71	12.388,39	817,633	3.220,98
64	15.178,58	1.001,78	3.946,43
53	18.601,19	1.240,53	4.836,071
	Two years after planting		
100	14.027,78	925,833	3.647,23
71	23.125,00	1.526,25	6.012,50
64	28.833,34	1.870,00	7.366,67
53	34.722,22	2.315,66	9.027,33
	Three years after planting		
100	21.041,67	1.388,75	5.470,83
71	34.687,50	2.289,375	9.018,75
64	42.500,01	2.805,001	11.050,00
53	52.083,33	3.473,500	13.541,00

Note: These values were obtained for 10% of the *An* population and then extrapolated to 1 ha. The machine has an average profit of 7% for fibre and 26% for mucilage.

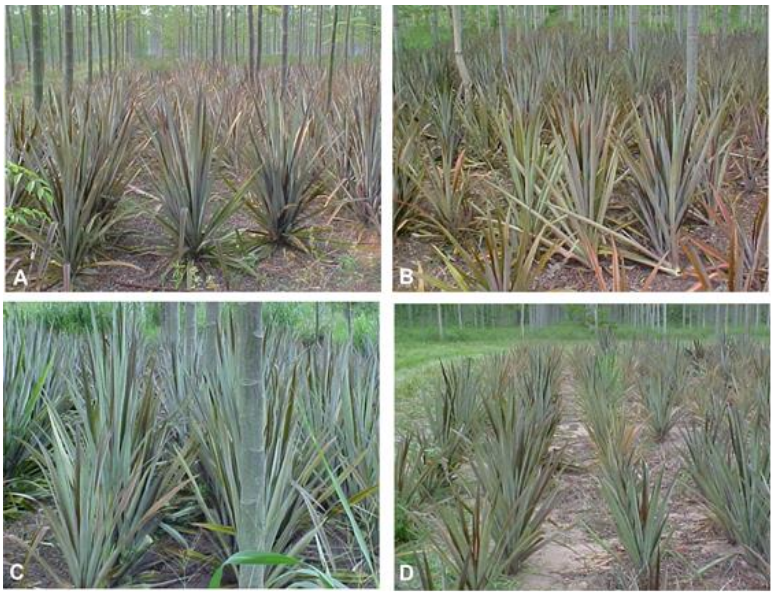

Fig 3. *Ananas* var. *erectifolius* plants under different PAR levels: A) 71%; B) 64%; C) 53%; and D) 100%.

hydric equilibrium, allowing better carbon fixation and diminishing energetic consumption through transpiration and respiration (Díaz, 2001). In addition, this author noticed that the trees from the Leguminosae family, such as *Prosopis juliflora*, *Acacia macracantha*, *Caesalpinia coriaria*, *Erythrina velutina*, *Tabebuia billbergii* and *Geoffroea spinosa,* have frequently been used in this zone in association with cactus (*Cereus horrispinus, Opuntia caracasana* and *Acanthocereus tetragonus*) and bromeliads (*Bromelia humilis* and *Bromelia chrysantha*), which represent alternatives for management and agroforestry systems. Generally, *Ananas comosus* planted in shade use PAR more efficiently for growth compared with those that develop under full sunlight. Some species can develop in shade conditions because their photosynthetic mechanisms are better adapted to such conditions (Poggiani et al., 1992). In many cases, plants under full sunlight (heliophytes) can adapt better to the available solar radiation, most likely because the shade leaves respire with less intensity than the sun leaves to compensate for the reduced carbon gain in environments with low luminosity (Freitas et al., 2003). Results that confirm this observation are widely available in the literature, which leads us to the conclusion that the low availability of light is the main factor that affects species adaptation. In this way, physiologists and ecologists have indicated that a full understanding of the mechanisms involved in resource capture and their use, as well as their interactions with the environment, is an issue of paramount importance for correctly designing more sustainable production systems (Ong et al., 1996). Despite the observation that the PAR levels (which reach the lower stratum of the plants) lead to variations in *An* growth, colouring and strength, the outcome was satisfactory because the overall analysis of the obtained data allowed us to understand the production of leaves, fibres and mucilage until the third year. Based on the obtained data, it can be inferred that because this species can develop under a wide range of luminosity levels (53% to 100% PAR), cultivation management methods can be safely devised. Such an assessment allows us to consider this species as a good plant for temporary culture in agroforestry systems under the studied conditions until it is convenient to eliminate it. However, it is not possible to generalise or predict whether *An* growth and

Table 4. Farming systems and percentage average levels of photosynthetic radiation Active - PAR. Experimental field Tramontina, Aurora do Pará, 2007.

PAR	Growing system	Notation
100 %	*Ananas comosus* var. *erectifolius (An)$_{2003}$*	*An*$_{2003}$
71 %	*Schizolobium parahyba* subsp. *Amazonicum* + *Swietenia macrophylla* King + *Cordia goeldiana* Huber $_{2001}$ + *Ananas comosus$_{2003}$*	Sc+Sw+Cg$_{2001}$+An$_{2003}$
64 %	*Schizolobium parahyba* subsp. *Amazonicum* + *Cordia goeldiana$_{2002}$*+ *Ananas comosus$_{2003}$*	Sc+Cg$_{2002}$ + An$_{2003}$
53 %	*Schizolobium parahyba* subsp. *Amazonicum* + *Ananas comosus$_{2003}$*	Sc$_{2003}$ + An$_{2003}$

fibre quality will change when associated with other species and PAR levels. An additional study regarding fibre quality is currently being conducted based on the same materials and at the same site to fully clarify the effectiveness of this system. Finally, the plants presented a variety of responses to the tested environmental changes. *An* has been proven to be a highly resilient species that is capable of adapting to imposed conditions. These responses are related to the morphological, physiological and geneticfaculties of this species and to the scale (frequency and magnitude) of the environmental manipulations that are endured by the plants. Thus, to expand the cultivation area, one must consider factors other than PAR and the association of *An* with other economically relevant species to reach more accurate conclusions. These conclusions could allow users to choose the best agroforestry systems for large and already altered/disturbed areas in the region and help small farmers recover economically.

Materials and Methods

Site description

This experiment was conducted at the experimental site of the Tramontina Belem S.A (2º10'00'' S, 47º32'00'' W) company in Aurora do Para county (PA-Pará State, Brazil). This experimental site belongs to the company's "Degraded Areas Recovery Project", and it covers an area of 1.043 hectares. The soil, which is classified as a yellow latosol with a sandy clay texture, has a low degree of organic matter, a low pH, very low levels of N and P and is highly leached. In addition, the soil is characterised by strong degradation due to cattle-raising activities and is widely covered by "quicuio" lawn (*Brachiaria humidicola*) from Amazonia and other invader species. The area is generally flat with only a slight undulated/wavy relief in the lower plateau of the Amazonas. The predominant climate in the region, according to the Thornthwaite Classification, is Br A'a, which is defined as tropical humid. The site's pluviometric annual average precipitation is 2.200 mm, with an annual average temperature of 26ºC. However, the hottest month presents an average temperature of 35ºC and an average relative humidity of 74%, according to the company's data register.

Experimental design

There were 1176 forest plants including 1040 *Schizolobium parahyba (Sc)*, 96 *Cordia goeldiana* Heber – *frejo* (Cg), 40 mahogany, and 13.000 agricultural (*An*) plant species. From the combination of species, seven treatments were established that were installed in a completely randomised block design with split plots. The size of each plot was 18 m x 24 m, and there were four replicates per treatment, resulting in a total of 28 plots and an experimental area of 12.096 m²; the subplots were the observation times (6 months) over a period of 36 months.

Plant materials

This experiment was conducted using combined plantings of *Ananas comosus* var. *erectifolius* (*An*) in forests of different ages as follows: Simultaneous An and *Schizolobium parahyba* subsp. *amazonicum* (Huber ex Duck) Barneby (Sc), i.e., Sc_0An_0; An planted one year after Sc combined with *Cordia goeldiana* Heber – *frejo* (Cg) (Jenny Wood) planting, i.e., $Sc_1Cg_1An_0$; An planted two years after Sc combined with Cg (Jenny Wood) and Mahogany planted with *Swietenia macrophylla* King (Sw), i.e., $Sc_2Cg_2Sw_2An_0$; and a "single" planting, i.e., An_0.

Light treatments

An LI-190 SA quantum sensor and a pair of LI-light meters were used to determine the photosynthetically active radiation (PAR) levels under each studied condition. Over a period of 36 months, two types of measures were performed, one during the rainy season and the other during the dry season (lower rainfall than the rainy season). For each environmental condition, a random set of ten measurement points, which were monitored every 15 minutes from 7 am to 4 pm, were used. A control point was placed outside of the vegetative cover to determine the PAR under full sunlight. The average PAR values were obtained, their respective percentages were calculated as the inverse of the PAR, and they were proportionally compared with the control point values (full sunlight). Based on these values, the average values of sunlight absorbed by the *An* plants under the shade of the forest species were determined, which generated luminosity intensity treatments of 53%, 64%, 71% and 100% (full sunlight). To infer the growth of the species, the lengths of the leaves, the number of leaves and the number of sprouts were monitored every six months over a period of three years. The photosynthetically active radiation (PAR) under each condition was measured throughout the day using an LI-190 AS quantum sensor and a pair of LI-light meters. Two types of measurements were made, i.e., measurements during the rainy season and measurements during the less rainy season, over a period of three years (2003, 2004 and 2005). Ten measurement points were randomly established in each treatment; these points were monitored every 15 minutes from 07:00 to 16:00. A control point located outside the vegetation cover was used to determine the PAR in full sun.

The average PAR values were obtained and the radiation percentage levels were calculated relative to the control; these values were used to calculate the average light levels received by the *An* plants that were shaded by the forest species, which determined the light intensity treatments. The average PAR values and the radiation percentage values were obtained, which were calculated relative to the control area. These values were used to calculate the average light levels received by the *An* plants shaded by the forest species, which determined the light intensity treatments (Table 4).

Statistical analysis

The resulting data were analysed using a repeated measures analysis of variance using SYSTAT statistical and graphical software. The average values were compared using the SNK test, a test that is widely used for experiments with more than two treatments. The number of *An* sprouts was calculated as the total number of sprouts relative to the total number of measured plants per treatment multiplied by 100. To perform the analysis of variance, the number of leaves and sprouts were log transformed; the length variable was not transformed.

Conclusions

Testing different photosynthetically active radiation (PAR) levels on *An* plants under cultivation indicated that better leaf growth and sprout production were related to the lowest PAR (53% and 64%) levels. The cultivation of *An* in full sunlight can reduce the lengths of the leaves and inhibit sprout production. The growth of *An* was favoured in the shade up to at least 36 months, which is important to consider when establishing its use in different systems and when defining management strategies. The *An* fibre, leaf and mucilage production progressively increased until the third year of the study.

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