Development of tree species in an agroforest system in Nova Xavantina, Mato Grosso, Central Brazil

Desenvolvimento de espécies arbóreas em um sistema agroflorestal em Nova Xavantina, Mato Grosso, Brasil Central

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ABSTRACT
As the arrangement of the species is fundamentally important to guarantee the effectiveness of agroforestry systems, it is important to test different combinations of species with varying levels of economic potential. The study was based on the analysis of the initial development of an agroforestry system formed by native tree species and other plants of economic interest,
intercropped with green manure species under the edaphoclimatic conditions of Nova Xavantina in Mato Grosso, central Brazil. The study was conducted in an experimental plot on the Nova Xavantina campus of Mato Grosso State University. The plot was arranged in randomized blocks, in a simple agroforestry system of the alley type, with the plants arranged in rows, in a 4x2 factorial design (four fruit species x two legumes). The fruiting species included five trees – Bixa orellana, Spondias lutea, Byrsonima crassifolia (L.) Rich, Pouteria ramiflora, and Theobroma grandiflorum, and the banana, Musa sp. (the “BRS Princesa” cultivar). Two combinations of legume species were tested – (i) Cajanus cajan and Vigna unguiculata, and (ii) Mucuna aterrima and Canavalia ensiformis. Tree growth was assessed based on four phytometric parameters – plant height, stem diameter, the number of leaves, and percentage survival, while for Musa, the parameters were height and pseudostem circumference, and the number of active leaves and shoots. Bixa orellana and S. lutea were the species best adapted to the edaphoclimatic conditions found in the experimental plot, with all (100%) of the Bixa plants surviving throughout the study, and a survival rate of over 70% in S. lutea.

**Keywords**: agroforestry system, fruiting species, green manure, survival.

1 **INTRODUCTION**

Agroforestry systems (AFSs) are a type of land management that combines trees with crops or pasture (Götsch, 1996). The most widely-used concept of an agroforestry system is that
adopted by World Agroforestry (ICRAF), which defines an AFS the a set of technological practises that combine the cultivation of tree species with herbaceous cash crops.

In 2017, 491,400 rural establishments in Brazil were registered as using some type of agroforestry system, covering a total area that corresponds to 1.63% of the total land area of Brazil (IBGE, 2017). In the state of Mato Grosso alone, the area dedicated to AFSs is the equivalent of 0.43% of the land area of Brazil, which represents an increase of 126% in comparison with 2006 (IBGE, 2012, 2017).

Once established, an agroforestry system may reduce significantly the use of external resources for the cultivation of the crops, given that the system is capable of replacing the nutrients required by the plants, thus reducing both operational costs and the need for artificial fertilizers (Götsch, 1996). In addition to these benefits, agroforestry systems permit the use of green manure through intercropping, which further enhances the independence of the farmer, who is able to use a natural and sustainable form of fertilization, by harvesting the seeds of these plants to sow them in subsequent years.

Agroforestry systems may also be managed for the production of commercial crops, including plants that can be used as food, or for the production of medicines, fibers, seeds, primary resources, and energy (Miccolis et al., 2016), which can be consumed by the farmer and/or sold. This means that agroforests not only guarantee food security and provide important resources for farmers, but can also diversify their potential sources of income.

The farmers and traditional communities that have experience with agroforestry systems tend to prefer native tree species or at least species that are ecophysiollogically similar to the native options. These preferences are derived from the knowledge accumulated over the years by the local residents, which greatly facilitates the exploitation and marketing of their produce (Götsch, 1996).

Despite the progressive expansion of this type of land use management and the increasing integration of commercial crops, data on the Cerrado are still scarce. Unfortunately, the few studies that do exist have shown that many barriers and limitations exist for the more widespread adoption of agroforestry systems.

In the Cerrado biome, where the present study took place, the principal causes of the failure of AFSs at a local scale include limiting factors in the physical environment, a lack of resources, and inadequate agroforestry planning (Miccolis et al., 2016). Given this, it is clear that
adequate planning will depend on a systematic understanding of the plant species to be used in an agroforestry system, as well as the development of effective agroecological practices that will ensure that the operation is able to overcome the limitations of the environment and the access to resources.

In addition to the selection of adequate species, it is essential to consider carefully the other factors that may influence the arrangement of the system. These factors may include the basic structure of the operation, related to the selection of the intercropping components, the temporal and spatial stratification of the system, functional questions, such as the factors that motivated the implantation of the system, the commercial perspectives of the operation, and ecological considerations, which will determine the arrangement of the system in accordance with the edaphoclimatic conditions of the region (Nair, 1989). The objectives are to analyze the initial development of different species of commercial interest in agroforestry systems, under the edaphoclimatic conditions found in Nova Xavantina, in Mato Grosso state, central Brazil.

2 MATERIAL AND METHODS

The study was conducted in an experimental plot on the Nova Xavantina campus of Mato Grosso State University. The plot was arranged in randomized blocks, in a simple agroforestry system of the alley type, with the plants arranged in rows, in a 4x2 factorial design (four fruit species x two legumes). The plot was arranged in randomized blocks, in a simple agroforestry system of the alley type, with the plants arranged in rows, in a 4x2 factorial design (four fruit species x two legumes). The fruiting species included five trees – *Bixa orellana*, *Spondias lutea*, *Byrsonima crassifolia* (L.) Rich, *Pouteria ramiflora*, and *Theobroma grandiflorum*, and the banana, *Musa* sp. (the “BRS Princesa” cultivar). Two combinations of legume species were tested – (i) *Cajanus cajan* and *Vigna unguiculata*, and (ii) *Mucuna aterrima* and *Canavalia ensiformis*.

Three phytometric parameters were obtained for the fruit trees: (i) the height of the plant (cm), determined using a measuring tape, with the measurement being taken from the base of the stem to the apical bud; (ii) the diameter of the stem (mm), measured using a digital caliper at a height of 10 cm above the ground, and (iii) the total number of active leaves. As *Bixa orellana* became reproductively mature by June 2020, it was excluded from the analysis of the growth of the species at this moment.
In the specific case of the banana the measurements were: (i) the height of the plant (cm), determined using a measuring tape from the base of the plant to the intersection of the uppermost open leaf; (ii) the circumference of the pseudostem (cm) at a height of 10 cm above the ground; (iii) the number of active leaves, and (iv) the number of shoots.

Given the growth patterns observed in the fruit tree species during the experiment, the data were divided into six different moments, corresponding to the three-monthly sampling periods. Moments A, B, C, and D were in March, June, September, and December 2019, respectively, and represent the 3rd, 6th, 9th, and 12th months after the implantation of the agroforestry system, respectively. Moments E and F were in March and June 2020 (15 and 18 months after the implantation). The growth data were evaluated using an Analysis of Variance (ANOVA), with a $p \leq 0.05$ significance level. When significant variation was identified, pairs of means were compared using Tukey’s test, with a $p \leq 0.05$ significance level, which was run in SISVAR 5.7.

3 RESULTS AND DISCUSSION

The Figures 1, 2, and 3 show the mean phytometric parameters (height of the plant - cm, diameter of the stem - mm and the number of leaves) of the tree species at the different moments of evaluation. *Bixa orellana* was not evaluated at moment F due to the initiation of its reproductive period.
Figure 1. Mean height (cm) of the tree species in the agroforestry system on the UNEMAT experimental farm in Nova Xavantina, Mato Grosso (Brazil) at the six moments of evaluation.

Moments: A – 3 months after the implantation of the agroforestry system; B – 6 months after the implantation of the agroforestry system; C – 9 months after the implantation of the agroforestry system; D – 12 months after the implantation of the agroforestry system; E – 15 months after the implantation of the agroforestry system; F – 18 months after the implantation of the agroforestry system.

Source: Author

*Bixa orellana* and *Theobroma grandiflorum* reached their maximum mean heights at the end of the study period (Figure 1), with *Bixa orellana* reaching a mean height of 156.61 cm at moment E and *T. grandiflorum*, a mean of 39.26 cm at moment F. The maximum mean height of *S. lutea* (92.57 cm) was also recorded at moment E (15 months), while that of *P. ramiflora* (18.50 cm) was recorded at moment C, and *Byrsonima crassifolia* (35.00 cm) at moment A.

The maximum mean stem diameter of *Bixa orellana* and *T. grandiflorum* was also recorded at the end of the study, with a mean of 28.98 mm in the former species at moment E and 5.63 mm in the latter at moment F. Once again, the maximum mean diameter of *S. lutea* (29.57 mm) was also recorded at moment E (15 months), while that of *P. ramiflora* (2.84 mm) was recorded at moment C, and that of *Byrsonima crassifolia* (3.7 cm) at moment A (Figure 2).
Figure 2. Mean stem diameter (mm) of the tree species in the agroforestry system on the UNEMAT experimental farm in Nova Xavantina, Mato Grosso (Brazil) at the six moments of evaluation.

Moments: A – 3 months after the implantation of the agroforestry system; B – 6 months after the implantation of the agroforestry system; C – 9 months after the implantation of the agroforestry system; D – 12 months after the implantation of the agroforestry system; E – 15 months after the implantation of the agroforestry system; F – 18 months after the implantation of the agroforestry system.

Source: Author

Miranda and Valentim (2000) recorded lower values of height and diameter in *S. lutea* after 12 months of growth in the Amazon region. These findings reinforce the more favorable edaphoclimatic characteristics found for the development of this species in savanna-type environments (Cerrado).

The largest mean number of active leaves (Figure 3) was recorded in both *Bixa orellana* and *S. lutea* at moment D (12 months after planting), with 439.94 and 22.43 leaves, respectively. The largest mean number of active leaves (10.65) was also recorded at moment D for *T. grandiflorum*. *Byrsonima crassifolia* reached a mean of 1.42 leaves in moment A, while *P. ramiflora* peaked at a mean of 5.58 leaves at moment C.
The phytometric parameters recorded during the present study vary considerably. However, it is possible to confirm that the species that presented the highest values for these parameters at the different moments of moments have specific characteristics, which provide important insights for the development and adaptation of the species to the system, related directly to the height of the plant, diameter of its stem, and the number de leaves. Despite this considerable variability in their growth patterns, *Bixa orellana* and *S. lutea* were the species that developed best development in the system, reflecting the existence of both vertical (height) and horizontal stratification (diameter).

*Bixa orellana* reached a greater height with a larger number of leaves than *S. lutea* at all moments of evaluation. *Bixa orellana* also performed relatively well in terms of the mean height and diameter reached in a study of the initial development of different forest species for the restoration of degraded areas (Souza, 2013). These findings reinforce the use of *Bixa orellana* as a potentially valuable species for the restoration of degraded areas (Souza, 2013), as well as for
agroforestry systems that aim for the recuperation of habitats, in addition to the production of marketable resources.

3.1 DEVELOPMENT OF THE BANANA (MUSA SP. CV. “BRS PRINCESA”) IN THE AFS

The banana reached their maximum mean height and pseudostem diameter (Table 1) at moment D, with a height of 1.30 m and circumference of 43.94 cm. In a study of the same cultivar in the municipality of Vera Cruz, in the Brazilian state of São Paulo, Martins et al. (2020) also recorded a mean height of less than 2.0 m and mean circumference of less than 50 cm at the time of first flowering.

Table 1. Mean phytometric parameters recorded for the banana (Musa sp. cv. “BRS Princesa”) planted in the agroforestry system on the UNEMAT experimental farm in Nova Xavantina, Mato Grosso (Brazil) at the six moments of evaluation.

<table>
<thead>
<tr>
<th>Moment</th>
<th>Pseudostem:</th>
<th>Number of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height (cm)</td>
<td>Circumference (cm)</td>
</tr>
<tr>
<td>A</td>
<td>40.71</td>
<td>21.36</td>
</tr>
<tr>
<td>B</td>
<td>75.47</td>
<td>24.59</td>
</tr>
<tr>
<td>C</td>
<td>107.78</td>
<td>35.33</td>
</tr>
<tr>
<td>D</td>
<td>130.2</td>
<td>43.94</td>
</tr>
</tbody>
</table>

Moments: A – 3 months after the implantation of the agroforestry system; B – 6 months after the implantation of the agroforestry system; C – 9 months after the implantation of the agroforestry system; D – 12 months after the implantation of the agroforestry system; E – 15 months after the implantation of the agroforestry system; F – 18 months after the implantation of the agroforestry system.

Source: Author

In a second municipality in São Paulo, Paraquera-Açu, Nomura et al. (2013; 2016) evaluated the development of the same cultivar with the application of mineral fertilizer. The plants reached a height of over 2 m during the first cycle, which hampered maintenance and the collection of the bunches of bananas, and a pseudostem circumference of greater than 60 cm. In the humid tropical climate of the Brazilian state of Bahia, the same cultivar reached a height of 4.22 m and a circumference of 59.66 cm during the first cycle (Velame, 2015). Plants of lower height, such as those observed in the present study, may facilitate the work of pruning and harvesting the bananas.

The mean number of leaves found on the banana plants remained stable throughout the study period, at between eight and nine. This was also a relatively low number in comparison
with other studies which have recorded between 10 and 17 leaves on plants of the same cultivar (Nomura et al., 2013, 2016).

At the last moment (F), the banana plants reached the highest mean number of shoots (1.83), despite the paring of the plants. This indicates that, when the mother plant is felled at harvest time, the plant will regrow, guaranteeing the longevity of the crop in the area (Bolfanaria et al., 2014). In addition to its importance for the longevity of the plantation, surplus shoots can also be transferred to new areas by the farmer (Maia et al., 2008).

The phytometric characteristics of the banana plants were aligned closely with the edaphoclimatic conditions of the region, and the cultivar appeared to be well adapted to the conditions of the system. The banana is a fruiting species widely used in AFSs, given its characteristic growth pattern, which can provide shade rapidly for the development of less tolerant species. The fruit is also a valuable resource for both subsistence and the generation of income, especially for family farms, on which intercropping is a common practise.

3.2 SURVIVAL OF THE TREE SPECIES IN THE AFS

The study species presented different patterns of survival over the different moments of evaluation, with some species being replaced by others during the course of the study. After the first three months, for example, almost all (100%) of the *Byrsonima crassifolia* (murici) plants were lost (Table 2). Botanical inventories of the Cerrado biome have shown that *B. crassifolia* is found in all its different phytophysiognomies (Miranda; Almeida; Dantas, 2006), although the largest numbers of individuals tend to be found in the areas of Cerradão (savanna woodland), which has a denser canopy and cooler microclimate in comparison with the initial implantation of the AFS. This indicates that this murici species is better adapted to climax environments.

*Spondia lutea* had a survival rate of more than 80%, while all the *Bixa orellana* individuals survived to the end of the study. After the first three months of the study (moment A), *Byrsonima crassifolia* was replaced by *Pouteria ramiflora* and new *S. lutea* seedlings were planted due to the fact that the system had not yet been fully establish and that this species had a high survival rate.
Table 2. Survival rates of the fruit tree species in the agroforestry system on the UNEMAT experimental farm in Nova Xavantina, Mato Grosso (Brazil) at the six moments of evaluation.

<table>
<thead>
<tr>
<th>Species</th>
<th>Percentage (% survival at moment:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Bixa orellana</td>
<td>100.0</td>
</tr>
<tr>
<td>Spondias lutea</td>
<td>88.9</td>
</tr>
<tr>
<td>Byrsonima crassifolia</td>
<td>16.7</td>
</tr>
<tr>
<td>Pouteria ramiflora</td>
<td>-</td>
</tr>
<tr>
<td>Theobroma grandiflorum</td>
<td>-</td>
</tr>
</tbody>
</table>

Moments: A – 3 months after the implantation of the agroforestry system; B – 6 months after the implantation of the agroforestry system; C – 9 months after the implantation of the agroforestry system; D – 12 months after the implantation of the agroforestry system; E – 15 months after the implantation of the agroforestry system; F – 18 months after the implantation of the agroforestry system.

Source: Author

Pouteria ramiflora declined rapidly in the system, passing from a survival rate of 77.78% at moment B to less than 35% at moment C, when it was replaced by Theobroma grandiflorum. Spondias lutea and Bixa orellana maintained survival rates of over 90% during this period.

In surveys of natural environments in central Brazil, P. ramiflora has been found primarily in well-structured habitats with a dense canopy, as found in the Cerrado-Amazon transition forest and Cerradão woodland, rather than more open, savanna-like habitats or regenerating environments (Gomes et al., 2018; Daronco; Melo; Durigan, 2013), which would likely account for its reduced survival in the initial stages of the AFS in the present study. The results of the study of Melo; Durigan; Kawabata (2004), which involved the experimental regeneration of different tree species in the Cerrado, support this conclusion, given that P. ramiflora was one of the species that performed least well over the first year of monitoring, with reduced phytometric parameters and a survival rate of less than 35%.

The initial development of P. ramiflora was more dependent on better structured environments, which indicates that further research is needed to better understand the development of this species in agroforestry systems in the Cerrado biome. The species is clearly unsuitable for use as pioneer species for the establishment of areas of regeneration.
More than 75% of the individuals of the species *T. grandiflorum*, *S. lutea*, and *Bixa orellana* survived over the second half of the study (moments D, E, and F). In a study of the implantation of *T. grandiflorum* in the Amazon region, Rayol and de Oliveira Alvino-Rayol (2019) recorded a higher survival rate when the species was introduced into the system when the existing tree species had reached a sufficient height to provide shade, in comparison with a recently-established system. The high survival rate recorded in the present study may thus be related to the introduction of *T. grandiflorum* into the system when it was at its most stable, when the banana, *S. lutea* and *Bixa orellana* had formed an adequate level of shade.

The results of the survival of *S. lutea* contradict the study of Miranda; Valentim (2000) in the Amazon region, in an area previously used for growing pasture, but subsequently covered with humid forest, where the mortality rate was over 30% at 12 months of age (Miranda; Valentim, 2000).

*Bixa orellana* and *S. lutea* were the species best adapted to the edaphoclimatic conditions found the study plot, with survival rates of over 70% for *S. lutea* and of 100% for *Bixa orellana* at all the moments of the study. This supports the inclusion of these two species as a priority for the establishment of agroforestry systems in the study region.

Nieri et al. (2017) suggested that, in addition to the adaptation of the plant to the local edaphoclimatic conditions, tree species that present high survival rate in agroforestry systems may also have a greater capacity to overcome the intra- and inter-specific competition encountered in the system. This may be true for *Bixa orellana* and *Spondias lutea* in the present study, given their arrangement in the experimental plot.

4 CONCLUSIONS

The different combinations of green manure species did not vary in their effects on the development of the fruiting species evaluated in the agroforestry system.

The achiote (*Bixa orellana*) was the fruit tree best adapted to the edaphoclimatic conditions of the system, with a 100% survival rate at all the moments of evaluation, and the best growth rates in terms of the phytometric parameters evaluated. The cajá (*Spondias lutea*) also appeared to be well-adapted to the system with survival rates of over 70% at all the different moments of evaluation.
Neither *Byrsonima crassifolia* nor *Pouteria ramiflora* were well adapted to the conditions of the agroforestry system, however, with low survival rates. Neither species is appropriate for inclusion in the initial stages of the agroforestry system.

The phytometric characteristics of the “BRS Princesa” banana cultivar were closely linked with the edaphoclimatic conditions of the region, and the plant was well-adapted to the conditions of the agroforestry system.
REFERENCES


