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Desenvolvimento de mudas arbóreas em sistemas agroflorestais na Terra Indígena Andirá-Marau, Amazônia Central, Brasil

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Manaus, Amazonas

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Orientador: Sônia Sena Alfaia

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Sinopse:

Estudou-se o desempenho inicial de mudas plantadas em diferentes sistemas agroflorestais localizados na Terra Indígena Andirá-Marau, Amazonas. Foram avaliados aspectos como fatores ambientais e manejo dos produtores indígenas.

Palavras-chave: Plantios de mudas, desempenho vegetal, manejo, structural equation modeling

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TÍTULO: *"TREE SEEDLING PERFORMANCE IN AGROFORESTRY SYSTEMS (INDIGENOUS RESERVE ANDIRÁ-MARAU, CENTRAL AMAZON, BRAZIL)"*

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Resumo

Sistemas agroflorestais são formas de uso da terra utilizadas por muito tempo ao redor do mundo. Atualmente tem-se prestado maior atenção a essa prática, com diversos projetos e organizações trabalhando com a otimização das técnicas, para um melhor desenvolvimento desses sistemas. Dentre as diversas maneiras de se estabelecer um sistema agroflorestal, levando em consideração as espécies a serem utilizadas, o ambiente em que se encontra e o tipo de sistema a ser implementado, o entendimento dos fatores que possam influenciar os plantios são de suma importância para um maior sucesso desses. O presente trabalho teve como objetivo avaliar o desenvolvimento inicial de mudas de 16 espécies plantadas em diferentes ambientes, pela influência de fatores ambientais e do manejo de agricultores locais. O estudo foi realizado na Terra Indígena Andirá-Marau (Amazonas - Brasil) e contou com oito diferentes plantios em ambientes com diferentes práticas agrícolas. Foram avaliados os parâmetros de desempenho vegetal o Estoque de Carbono (CARBON), o Incremento Absoluto do Diâmetro (ADI), a Taxa de Crescimento Relativo (RGR) e a Área Foliar Específica (SLA). Como fatores de influência no desempenho das mudas foram avaliados: a Qualidade dos Solos (química e física), a porcentagem de Cobertura Vegetal (VC), a Distância dos plantios para a Floresta (FD), Biomassa Acima do Solo (AGB), Riqueza de Espécies (SP_RICH), Biomassa da Serrapilheira, Biomassa de Carvão, Vizinho Próximo das mudas plantadas e Índice de Competição. Como análise descritiva, os solos foram analisados utilizando o teste ANOVA (two-factor) entre as profundidades e a áreas. Também de forma descritiva foram analisados os plantios quanto: sobrevivência das mudas, composição de espécies, espaçamento, altura e biomassa. Para análise dos dados foram utilizadas regressões lineares entre cada medida de desempenho e cada fator de influência, como forma exploratória dos dados. Posteriormente utilizo-se a análise Structural Equation Modeling (SEM) para testar como os fatores influenciam o desempenho das mudas de forma conjunta. Por fim, para testar como os modelos gerais para todas as espécies influenciam de maneira específica, foi testado modelos para a espécie *Carapa guianensis* Aubl. Como resultado, pode-se observar que ao longo do projeto 45% das mudas morreram (9% entre Dez 2014 e Dez 2015, 32% entre Dez 2015 e Ago 2016, 11% entre Ago 2016 e Fev 2017), devido principalmente a grande seca no 2º. semestre de 2015. As espécies Ingá, Urucum, Andiroba e Graviola mostraram grande variabilidade no acumulo de biomassa, enquanto Acerola, Cumaru, Guaraná e Mogno variaram muito menos. Já a análise exploratória nos mostrou que o RGR foi influenciado positivamente por FD e pelos nutrientes do solo Mn, Ca, Mg, K e CEC e negativamente por Fe; o Estoque de Carbono foi influenciado positivamente por FD, Biomassa de Carvão, Vizinho Próximo, pelos nutrientes do solo Al, Mg, K, C, N, CEC e negativamente por Densidade do Solo e Fe; o ADI foi influenciado positivamente por FD, Vizinho Próximo, pelos nutrientes Al, Mg, K, C, N, CEC e negativamente por Densidade do Solo e Fe; SLA foi influenciada positivamente por VC e AGB. Nos modelos gerais para todas as espécies, em SEM, vimos que o Estoque de Carbono teve 14% de variação explicada pelo modelo, ADI teve 14%, RGR teve 11% e SLA teve 10%. Para o modelo específico (*Carapa guianensis)* a porcentagem de variação explicada pelos modelos foram, Estoque de Carbono com 31%, ADI com 27 %, RGR com 10% e SLA com 71%. Podemos concluir que os fatores do solo (C, N, P, Mg, CEC, pH, Textura e Densidade), Biomassa da Serrapilheira, VC e Vizinho Próximo, tiveram maior influência no desempenho inicial das mudas nos sistemas agroflorestais implantados, devendo ser levadas em consideração nas práticas de manejo.

Abstract

Agroforestry system is a land use technique practiced a long time around the world. Currently, an attention has been paid to this practice, with several projects and organizations working with the optimization of this technique. Among many ways of establishing an agroforestry system, taking into account the species to be used, the environmental conditions and the type of system to be implemented; the understanding of the specific factors that can influence the plantations are of utmost importance for its success. The present work aimed to evaluate the initial development of seedlings from 16 species planted in different lands, influenced by environmental factors and management of local farmers. The study was carried out at the Andirá-Marau Indigenous Reserve (Amazonas - Brazil) in eight different plantations with different agricultural practices. The parameters of plant performance analyzed were: Carbon Stock (CARBON), Absolute Diameter Increment (ADI), Relative Growth Rate (RGR) and Specific Leaf Area (SLA). As factors influencing the performance of seedlings were analyzed: Soil Quality (chemical and physical), percentage of Vegetation Cover (VC), Forest Distance (FD), Above Ground Biomass (AGB), Species Richness (SP_RICH), Litter Biomass, Charcoal Biomass, Nearest Next Neighbor and Competition Index. As a descriptive analysis, the soils were analyzed using ANOVA (two-factor) testing soil depths and areas. Also, the plantations were analyzed in terms of: area size, seedling survival, species composition, spacing, height and biomass. As an exploratory data analysis we used linear regressions between each performance trait and each influence factor. Later, we used the Structural Equation Modeling analysis to test how the factors together influence the performance of the seedlings. Finally, to test how the general models for all species influence in a specie-specific way, we tested models for *Carapa guianensis* Aubl. As results, it can be observed that during the project 45% of the seedlings died (9% between Dec 2014 and Dec 2015, 32% between Dec 2015 and Aug 2016, 11% between Aug 2016 and Feb 2017), mainly due to large dry season on the 2nd semester. Ingá, Urucum, Andiroba and Graviola species showed great variability in biomass accumulation, while Acerola, Cumaru, Guaraná and Mahogany varied much less. The exploratory analysis showed that RGR was positively influenced by FD and soil nutrients Mn, Ca, Mg, K and CPB and negatively by Fe; the Carbon Stock was positively influenced by FD, Coal Biomass, Nearby Neighbor, by soil nutrients Al, Mg, K, C, N, CEC and negatively by soil Density and Fe; ADI was positively influenced by FD, Neighbor Next, by nutrients Al, Mg, K, C, N, CEC and negatively by soil Density and Fe; SLA was positively influenced by VC and AGB. In the general models for all species, in SEM, we could observe that Carbon Stock had a 14% variation explained by the model, ADI had 14%, RGR had 11% and SLA had 10%. For the specific model (*Carapa guianensis*) the percentage of variation explained by the models was: Carbon Stock with 31%, ADI with 27%, RGR with 10% and SLA with 71%. We can conclude that soil factors (C, N, P, Mg, CEC, pH, Texture and Density), Biomass of Serrapilheira, VC and Next Neighbor, had greater influence on the initial performance of the seedlings planted in different agroforestry systems, which have to be taken into account for management practices.

Sumário

1. Introdução Geral

Os sistemas agroflorestais são formas antigas de uso da terra utilizadas ao redor do mundo (NAIR, 1993), com registros na Amazônia de vários milhares de anos atrás (MILLER & NAIR, 2006). Como conhecido por muitos estudiosos da área: “um conceito novo para uma prática antiga”; os sistemas agroflorestais passaram a ser foco da pesquisa científica no fim da década de 1970 (van LEEUWEN, 2011). Apesar do grande arcabouço teórico e das inúmeras definições, uma definição prática de sistemas agroflorestais seria o uso de árvores na agricultura (van LEEUWEN, 2013). Como foco do presente estudo, o componente arbóreo dos sistemas agroflorestais traz diversos benefícios para o ambiente (RAO, NAIR & ONG, 1998; LEAKEY, 2014), além dos benefícios para produtividade do sistema (PALM, 1995).

Um dos principais interesses nos sistemas agroflorestais é a sua produção (NAIR, 1993). A produção está relacionada com a quantidade de recursos de interesse humano (ex. frutos, sementes, madeira, etc.) por área. O rendimento de uma colheita é determinado pela produção total de matéria seca, a distribuição da matéria seca entre os componentes vegetais (flores, frutos, folhas, galhos e raízes) e o teor de matéria seca dos frutos (MARCELIS, HEUVELINK & GOUDRIAAN, 1998). Portanto, sistemas que apresentem melhor desempenho (maior eficiência na utilização de recursos para produção de biomassa) apresentem também maior produção de bens. É bem conhecido que o desempenho das plantas é influenciado pela sua genética, estágio ontogenético e condições ambientais (GRIME & HUNT, 1975). No presente estudo foram implementados oito novos sistemas agroflorestais, seguindo o mesmo método, composição de espécies e tamanho dos indivíduos arbóreos, porém em ambientes diferentes. Portanto, os fatores genética e ontogenia foram assim reduzidos (por serem utilizadas mudas do mesmo tamanho e provenientes da mesma região), tendo como fator determinante as condições ambientais de cada área. Como condições ambientais, consideram-se aqui quatro principais características de influência no desempenho vegetal: *Recursos*, relacionado com a disponibilidade local de recursos para as plantas (Qualidade nutricional do Solo e Serrapilheira); *Condições*, relacionada com a forma com que o ambiente está estruturado (Distância da Floresta, Biomassa Acima do Solo, Riqueza de Espécies, Cobertura Vegetal e Física do Solo); *Competição*, como a partilha de recursos entre os componentes arbóreos e os outros indivíduos está afetando o crescimento (Vizinho Próximo e Índice de Competição); e *Manejo*, qual a influência do fator humano no desempenho das mudas (Relacionados com o Histórico de Uso e Manutenção - Tempo do

Ultimo Fogo, Vezes Fertilizados, Biomassa de Serrapilheira e Manejo da Sombra). Esses serão exemplificados no decorrer do trabalho.

Portanto, o entendimento das interações ecológicas que ocorrem nesses sistemas pode ajudar nas práticas de manejo, favorecendo processos naturais e interações biológicas que otimizem as sinergias, auxiliando assim a produção das culturas (ALTIERI, 2002). Com isso o presente estudo busca avaliar as influências bióticas e abióticas no desenvolvimento inicial de sistemas agroflorestais. Mais precisamente como as características de Recursos, Estrutura, Competição e Manejo influenciam o Desempenho (Estoque de Carbono, Incremento Absoluto do Diâmetro, Taxa de Crescimento Relativa e Área Foliar Específica) de sistemas agroflorestais.

Este trabalho fez parte de um projeto maior denominado Waraná, que contou com o patrocínio do Programa Petrobras Socioambiental, foi desenvolvido na Terra Indígena Andirá-Marau em parceria como o Consórcio dos Produtores Sateré-Mawé. O projeto visa a melhoria dos sistemas de produção agrícola por meio de práticas alternativas de manejo da terra, a partir da implementação de unidades referência de sistemas agroflorestais. Com isso, busca-se amenizar a degradação ambiental de cultivos convencionais, favorecer o acúmulo de carbono e conservação da fertilidade dos solos, garantir estabilidade produtiva e gerar conhecimento e informações sobre métodos de plantio mais adequados para as espécies nativas da região.

2. Justificativa

O entendimento dos fatores ambientais que influenciam o desenvolvimento dos agroecossistemas Amazônicos é importante para aprimorar as técnicas de manejo, aumentar a eficiência e produtividade desses sistemas, fazendo com que as comunidades indígenas possam continuar explorando os recursos naturais por mais tempo, com impactos minimizados e aumentar a disponibilidade de bens durante todo ano.

3. Objetivo Geral

Avaliar como os fatores ambientais e o manejo dos agricultores locais influenciam o desempenho inicial de mudas arbóreas em diferentes sistemas agroflorestais implantados em áreas de produtores indígenas.

3.1. Objetivos Específicos

Mais especificamente, os objetivos deste trabalho são: verificar como os fatores *Recursos, Condições, Competição e Manejo,* influenciam o desempenho das mudas arbóreas plantadas em diferentes sistemas agroflorestais.

4. Revisão Bibliográfica

4.1. Sistemas Agroflorestais

Uma forma antiga de manejo e uso da terra, comumente utilizada ao redor do mundo (NAIR, 1993), são os sistemas agroflorestais. Esses sistemas consistem basicamente em práticas de cultivo agrícola juntamente com espécies lenhosas e/ou criação de animais na mesma unidade de terra (NAIR, 1991; SANCHEZ, 1995). A idéia do sistema agroflorestal (SAF) é otimizar as relações ecológicas entre seus componentes, e assim, fazer com que o sistema se auto-sustente, não necessitando ou diminuindo ao máximo o uso de insumos externos. O principal objetivo do SAF é a busca do sucesso no uso da terra para atingir o aumento da produção e a estabilidade ecológica. Para isso o sistema necessita de técnicas no uso racional da água e do solo, diversificar a produção de bens, utilizar espécies de uso múltiplo e combinar o conhecimento tradicional dos agricultores com o conhecimento técnico/científico (NAIR, 1993).

As pesquisas em sistemas agroflorestais podem aumentar vastamente os benefícios desse modo de produção e para isso é necessário que hipóteses e argumentos sejam testados para que possa construir uma base sólida para o design de sistemas agroflorestais melhorados (NAIR, 1991), principalmente focando na sustentação das relações ecológicas e aumento da produção (SANCHEZ, 1995).

4.2. Desempenho Vegetal

O desempenho vegetal pode também ser considerado como produtividade primária. A produtividade primária de um ecossistema, ou agroecossistema, esta relacionada com os fluxos de energia e matéria, que são responsáveis pelas suas atividades e construção, respectivamente. Essa produtividade primária é a quantidade de biomassa/carbono (nas partes da planta: folhas, galhos, tronco, raízes, frutos, flores e sementes) produzida por unidade de área (TOWNSEND, BEGON & HARPER, 2010). A produção agrícola esta relacionada com a produção de bens agroflorestais (frutos, sementes/castanhas, folhas, madeira, óleos essenciais, entre outros). Portanto, espera-se que ambientes mais produtivos (maior produtividade primária) também apresentem maior produção de bens. Como exemplo, VALE et al. (2014) constataram que o maior potencial produtivo da castanha de cajú estava relacionado com maiores tamanhos das plantas (altura e diâmetro da copa), mostrando que plantas da mesma espécie com maior produtividade primária(maior acúmulo de biomassa) apresentaram maior produção (agrícola). Algumas formas de medir a produtividade primária de sistemas agroflorestais podem ser:

Estoque de Carbono

O estoque de carbono é o processo de remoção de C da atmosfera e seu depósito em uma reserva. É a transferência do carbono atmosférico (CO_2) para seu acúmulo nas plantas através do processo de fotossíntese e na matéria orgânica dos solos a partir dos processos químicos e biológicos de decomposição (humificação). Estima-se que o solo e a biomassa acima do solo podem estocar até 60% e 30% de carbono respectivamente, do total de carbono armazenado em sistemas de uso da terra que utilizam árvores (NAIR et al., 2010). Estima-se que sistemas agroflorestais têm o potencial de estocar cerca de 12% de todo o carbono terrestre do mundo (DIXON, 1995). O estoque de carbono nas plantas está diretamente relacionado com as características da espécie e a disponibilidade de recursos a ela fornecida (nutrientes e água). Além disso, o estoque de carbono no solo também depende da sua estrutura (agregação e porosidade) (NAIR et al., 2010).

Os componentes da vegetação, serrapilheira e características do solo, modificam a dinâmica e estoque de carbono nos agroecossistemas. Então, a eficiência do estoque depende de muitos fatores, desde condições ambientais até práticas de manejo (NAIR et al., 2010).

Uma forma de mensurar o estoque de carbono na biomassa vegetal é a produtividade primaria líquida (PPL), que pode ser dada pela diferença entre o carbono acumulado pela fotossíntese menos o que foi gasto na respiração, representando a taxa real de acúmulo de carbono em um certo intervalo de tempo (MONTAGNINI & NAIR, 2004; CLARK et al., 2001). Essa medida de desempenho (produtividade) é medida em Mg C $ha^{-1}ano^{-1}$.A taxa de estoque de carbono do solo também esta relacionada com a produtividade primária líquida (produtividade da vegetação crescendo em determinado solo), em que durante longos períodos de tempo parte da produtividade primária liquida (carbono) entra no solo como matéria orgânica e sai como CO_2 e CH_4 via ação microbiana (SMITH, 2008).

Incremento Absoluto do Diâmetro

O incremento absoluto do diâmetro (*ADI*, absolute diameter increment) é dado pelo incremento de diâmetro, dividido pelo período de tempo entre as medidas. Essa é uma medida simples e robusta de ser conduzida (pelo fácil uso dos equipamentos de mensuração, não havendo muita variabilidade na coleta de dados, reduzindo assim o erro amostral). É uma medida simples do crescimento vegetal utilizada em diversos estudos (FINEGAN, CAMACHO & ZAMORA, 1999; GOURLET-FLEURY & HOULLIER, 2000).

Taxa de Crescimento Relativo

A taxa de crescimento relativo (*RGR*, relative growth rate) é uma medida de crescimento ao longo do tempo que pode representar o potencial produtivo das culturas em geral. Ela representa o quanto a planta acumulou de biomassa ao longo do tempo relativo à medida inicial. É dada pela formula: RGR = (*Ln bf* - *Ln bi*) / (*dt*), onde *Ln* é o logaritmo natural, *bf* é a biomassa final, *bi* é a biomassa inicial e *dt* é o tempo final menos o tempo inicial (GRIME & HUNT, 1975). Essa pode ser uma importante medida de desempenho de plantios agroflorestais, como mostra FENG& LI (2007).

Área Foliar Específica

A área foliar específica (SLA, specific leaf area) representa a eficiência da biomassa foliar para a captura de luz. Em muitos casos, está positivamente relacionada com a taxa de crescimento relativo e taxa máxima de fotossíntese com base na massa (CORNELISSEN et al., 2003).É calculada pela área foliar dividido pela massa seca da folha, dada em m^2Kg^{-1} ou mm^2 mg^{-1}. Espécies em ambientes ricos em recursos tendem a ter alto valor de SLA enquanto espécies com baixo SLA apresentam folhas mais robustas (alto investimento em defesa (CORNELISSEN et al., 2003) e suas reservas duram mais tempo (FONSECA et al., 2000). Essa é uma característica funcional da planta que responde às condições ambientais, sendo uma resposta à perturbação e prevenção de stress (WEIHER et al., 1999).

4.3. Fatores limitantes do desempenho vegetal

O desempenho, ou crescimento, das comunidades de plantas terrestres depende de condições e recursos que possibilitem o processo da fotossíntese e a captura de elementos básicos para seu funcionamento, sendo basicamente, dióxido de carbono, água, nutrientes e radiação solar (Figura 1). O primeiro, apesar de apresentar grandes implicações com os aumentos globais de sua concentração na atmosfera (DELUCIA et al., 1999; NEMANI et al., 2003), é um fator comum a todas as comunidades locais. Já os outros fatores, podem mudar de um lugar para outro.

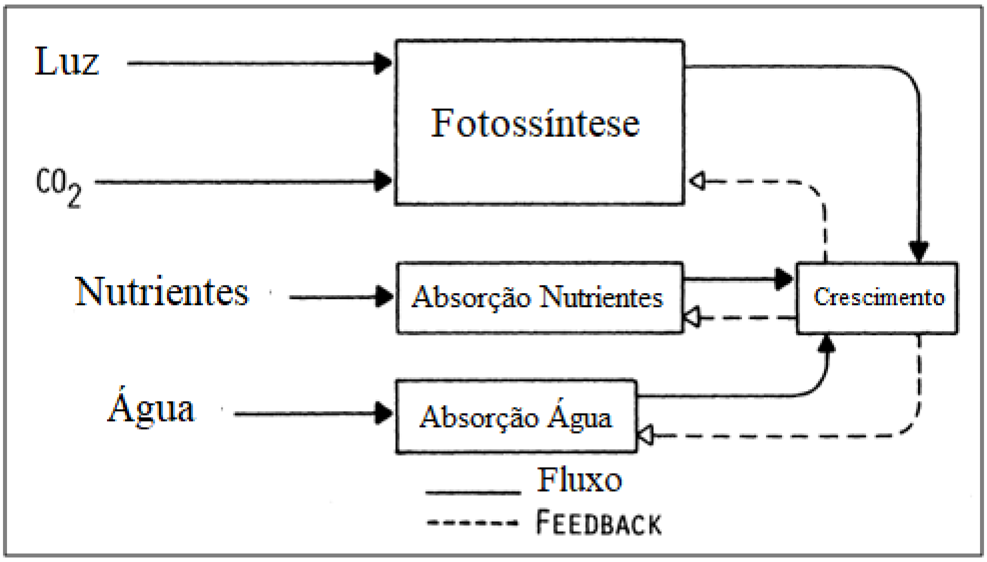

Figura 1. Fluxo e retorno dos fatores ambientais que afetam a aquisição de recursos e o crescimento das plantas (Adaptado de CHAPIN, 1991).

Um dos elementos fundamentais para o desempenho, presente em diversas estruturas e mecanismos da planta, é a água. O processo de expansão celular, causa do crescimento das plantas, é uma das atividades mais sensíveis ao stress causado pela falta d'água (HSIAO, 1973). A falta d'água também pode afetar a distribuição de compostos nas plantas, dependendo do estágio de desenvolvimento das plântulas e a sensibilidade das espécies ao stress hídrico (TURNER & BEGG, 1981). Para se aumentar a produtividade de agroecossistemas, é importante o entendimento das condições adequadas de suprimento de água que influenciam o crescimento das plantas (LAMBERS, CHAPIN III & PONS, 2008).

Assim como a água, os nutrientes são fatores que limitam fortemente a produtividade terrestre,assim como, diferentes ecossistemas respondem à adição de um ou mais nutrientes, apresentando limitações nutricionais em sua maioria (LAMBERS, CHAPIN III & PONS, 2008). A baixa disponibilidade de nutrientes no solo pode causar, entre outras coisas, diminuição na taxa fotossintética, aumento de problemas metabólicos, aumento da mortalidade, diminuição na concentração de nutrientes dos brotos e diminuição do crescimento da planta (CHAPIN, 1980).

Segundo LAMBERS, CHAPIN III & PONS (2008), a radiação solar apresenta uma intensidade ótima para um melhor funcionamento da fotossíntese de cada espécie, porém, dependendo da sua intensidade, pode ser um causador de stress nas plantas. Intensidades baixas de luminosidade limitam a fotossíntese, o estoque de carbono e o crescimento das plantas, podendo apresentar mal funcionamento da sua parte estrutural ou bioquímica. Já altas intensidades luminosas podem causar danos no aparato fotossintético das plantas.

Outro fator que tem grande influência no desempenho das plantas é a temperatura. À medida que a temperatura desvia do valor ótimo, as plantas modificam seus sistemas fisiológicos, metabólicos, bioquímicos e moleculares para maximizar o crescimento e manter a homeostase celular (GUY et al., 2008). Cada espécie apresenta sua temperatura ótima para o crescimento e sua distribuição está relacionada com a zona de temperatura na qual consegue sobreviver (IBA, 2002).

Características ambientais que têm relação direta com os fatores limitantes do desempenho vegetal e que podem estar presentes em agroecossistemas, podem ser divididos em quatro classes de influência: *Recursos* (disponibilidade de recursos no meio), *Condições* (estrutura da paisagem em que um agroecossistema está inserido), *Competição* (competição por recursos dos componentes do agroecossistema) e *Manejo* (influência humana nos agroecossistemas). Esses são exemplificados a seguir:

Recursos

Os recursos, como mencionado acima, são representados pela disponibilidade de nutrientes e água presente no agroecossistema, que são utilizados pelas espécies vegetais e que têm influência no seu desempenho.

Qualidade nutricional do solo

Um solo com qualidade para o desenvolvimento vegetal pode ser definido de acordo com a disponibilidade de nutrientes e sua textura, entre outros. O suprimento de nutrientes para a superfície da raiz depende das concentrações das soluções no solo, a capacidade de reabastecer os nutrientes na medida em que são absorvidos e pela taxa de circulação de nutrientes até a superfície da raiz por difusão ou por fluxo de água no solo (CHAPIN, 1980). Os íons limitantes para o crescimento das plantas, como fosfato (fósforo) e amônia (nitrogênio), que são facilmente adsorvidos pelo solo, têm baixas concentrações na solução do solo, dificultando sua difusão, limitando a velocidade de absorção pelas raízes das plantas (CHAPIN, 1980).

Serrapilheira ou Resíduo Vegetal

A matéria depositada ao solo pelos componentes do agroecossistema ou do seu entorno, tem grandes implicações nos fatores abióticos. Como, por exemplo, maior disponibilidade de nutrientes minerais ao solo, diminuição da incidência de luz no solo, diminuição da temperatura do solo, melhoria na dinâmica da água, e ainda efeitos adversos como, produção de fitotoxinas e barreiras para a germinação e estabelecimento de plântulas (FACELLI & PICKETT, 1991).

Porém a intensidade dessas influências varia de acordo com a composição das espécies. As diferentes espécies produzem diferentes quantidades e qualidades de serrapilheira, afetando a quantidade e qualidade da matéria orgânica do solo (SOM) e o tipo de micro-organismos que a decompõe (NAIR et al., 2010).

Condições

As condições do ambiente são aqui caracterizadas como a formação vegetal, a fisionomia e as características do entorno dos agroecossistemas que têm grande influência nos fatores limitantes do desempenho.

Biomassa acima do solo

A biomassa acima do solo pode ter um efeito facilitador no estabelecimento e desenvolvimento das espécies de interesse dos agroecossistemas (espécies alvo). Assim como a cobertura vegetal, a biomassa acima do solo pode melhorar as características climáticas e deposição de nutrientes, ajudando assim o desempenho do sistema.

A biomassa acima do solo também pode influenciar negativamente um agroecossistema. Pode ser que quanto maior a biomassa acima do solo maior a cobertura vegetal aumentando assim a competição por luz e possivelmente maior a quantidade de raízes, aumentando a competição por recursos do solo. Assim, se não for manejada da forma adequada, ela pode provocar diminuição do desempenho das espécies de interesse agroflorestal.

Riqueza de espécies

Existem muitos estudos dentro da ecologia a respeito da influência da riqueza de espécies no funcionamento dos ecossistemas. Segundo ALTIERI (1999), se manejada da forma correta, a biodiversidade pode levar agroecossistemas ao seu próprio sustento na fertilidade do solo, proteção das culturas e produtividade, assim, resultando em produções sustentáveis, conservação de energia e menor dependência em insumos externos. O plantio de espécies consorciadas pode promover processos de facilitação das espécies alvo, a partir da maior disponibilidade de recursos paras as plantas (água e nutrientes) ou pela regulação de pragas e doenças por agroecossistemas geneticamente diversos (BROOKER et al., 2016). Outros benefícios promovidos por agroecossistemas biodiversos que favoreçam o desempenho das espécies alvo, podem ser, aumento da ciclagem de nutrientes do solo (pela microflora e microfauna associadas), fixação biológica de nitrogênio, controle da erosão, além de outros serviços ecossistêmicos (GURR, WRATTEN & LUNA, 2003).

Cobertura Vegetal

A cobertura vegetal ocasionada pelo fechamento da copa das árvores de um sistema agroflorestal pode ter um efeito facilitador para as espécies componentes desse sistema. Isso acontece devido ao fato de a fotossíntese ser alimentada pela parte fotossinteticamente ativa do espectro de luz (LAMBERS, CHAPIN III & PONS, 2008), tendo uma radiação solar ótima para o desempenho vegetal. Portanto, dependendo da porcentagem de cobertura vegetal, pode haver um balanço entre disponibilidade de luz solar (menor cobertura) e melhores condições climáticas/maior disponibilidade de recursos (maior cobertura) como umidade e matéria orgânica, representando um efeito determinante no desempenho dos indivíduos presentes.

Por outro lado, a cobertura vegetal da copa das árvores de um sistema agroflorestal pode apresentar uma relação de competição. Dependendo do adensamento de indivíduos no sistema, esses podem passar a competir pela luz, o que pode acarretar na diminuição do desempenho do sistema. Como constatado por LEBRIJA-TREJOS et al. (2010), o aumento da área da copa em uma área de floresta tropical sazonalmente seca, ocasionou uma redução na densidade do fluxo de fótons utilizados no processo de fotossíntese.

Distância para a Floresta

Muitas propriedades agrícolas, mais especificamente na Amazônia, são estabelecidas em áreas anteriormente compostas por floresta ou capoeira. Uma pratica comum da agricultura de corte e queima, é a abertura uma área dentro da floresta para se realizar o plantio, resultando em áreas de plantio rodeadas por floresta, como o que acontece nos roçados de mandioca.

Essa vegetação no entorno pode influenciar nos fatores limitantes do desempenho, como umidade, nutrientes, temperatura e radiação solar. Segundo LAMBERS, CHAPIN III & PONS (2008), ambientes que apresentam o ar e solo secos, causam um stress nas plantas, fazendo com que fechem os estômatos nas horas mais quentes do dia e assim limitando o desempenho.

Física do solo

A textura dos solos, as proporções relativas de areia, silte e argila, basicamente, possibilitam inferir sobre a retenção de água e nutrientes. As argilas apresentam alta capacidade de retenção de água, plasticidade e coesão, diferente da areia que apresenta baixa capacidade de retenção de água e baixa coesão (HENIN, GRAS & MONNIER, 1976). Além da densidade dos solos que por um lado facilita o estoque de nutrientes e água (dependendo do grau de compactação do solo), por outro dificulta o desenvolvimento das raízes.

Competição

A competição é caracterizada como a inibição de um indivíduo por um outro na aquisição de recursos, ocorrendo quando indivíduos partilham os mesmos recursos disponíveis no meio. Indivíduos vizinhos podem se influenciar mutuamente por terem suas zonas de aquisição de recursos sobrepostas, como a aquisição de luz pelo sombreamento de uma sobre a outra, ou o menor acesso a água e nutrientes por indivíduos que apresentem raízes com a mesma profundidade que seus vizinhos competidores superiores (KEDDY, 2001). A competição é assim um forte mecanismo que pode influenciar o desempenho dos indivíduos de interesse para a produção agroflorestal.

Como órgãos de aquisição de água e nutrientes, as raízes apresentam várias características morfológicas que podem influenciar a competição entre as plantas. Quanto maior a densidade de raízes ou menor a distância entre elas, maiores as taxas de competição e logo, menor o desempenho individual. Para que espécies coexistam em um mesmo espaço, espera-se que apresentem estruturas de raízes diferentes (como por exemplo, profundidade), fazendo com que cada individuo explore os recursos do solo em compartimentos distintos, não havendo assim partilha de recursos. Um cuidado especial deve ser tomado no design de sistemas agroflorestais para impedir a interferência das raízes nas áreas, para isso, formas mais simples e confiáveis para a medição das interações entre as raízes necessitam de maior desenvolvimento futuro (SANCHEZ, 1995). Portanto formas de se estimar a competição entre plantas seria a distância entre a planta alvo e os vizinhos mais próximos (*Vizinho Próximo*) e a relação entre a biomassa dos vizinhos mais próximos e suas respectivas distâncias para a planta alvo (*Índice de Competição*).

Manejo

A partir da idéia de que o desempenho de um agroecossistema pode ser influenciado por fatores bióticos e abióticos, a influência humana, alterando o ambiente, tem então impacto direto no crescimento das espécies arbóreas plantadas nos sistemas agroflorestais.

Histórico de Uso

O histórico de uso de uma área diz respeito o quanto de alteração do meio e como a utilização dos recursos ali disponíveis anteriormente aconteceu. A maneira como o homem utilizou determinada área no passado pode nos dizer muito da qualidade do ambiente e como isso pode afetar o desempenho da vegetação local. Como por exemplo, a agricultura de corte e queima, muito praticada pelas comunidades amazônicas, que a partir da queima da biomassa vegetal contida no local, são disponibilizados os nutrientes antes contidos nas plantas, para o solo. Porém, devido às características dos ambientes de florestas tropicais, há uma rápida perda de nutrientes pela rápida taxa de decomposição, lixiviação, escoamento superficial, erosão, entre outros (SANCHEZ et al., 2005).

Manutenção

A manutenção ou manejo de um agroecossistema, também considerada uma influência humana no ambiente que pode ajudar no crescimento das espécies de interesse, é uma forma de garantir a sustentabilidade nas práticas agrícolas (PARROTTA, TURNBULL & JONES, 1997). Como parte de sistemas agrícolas, para garantir o ótimo crescimento das espécies arbóreas desejadas, práticas de manejo devem ser adotadas, como: capinar ou roçar a área na medida em que a muda cresce, plantio junto com o cultivo agrícola (ITTO, 2002), adubação verde, cobertura morta do solo, podas (MAY & TROVATTO, 2008), entre outras.

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6. Resultados

Os resultados do presente trabalho serão apresentados na forma de um artigo científico.

Tree seedling performance in agroforestry systems at the Indigenous Reserve Andirá-Marau, Central Amazon, Brazil

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6.1. Introduction

Agroforestry systems turned into a focus of scientific research in the late 1970s (van LEEUWEN, 2011). In tropical countries, agroforestry promotion became an important option for government and non-government organizations. This is especially true for the Amazon, where it is promoted as an environment-friendly alternative to shifting cultivation.

As agroforestry aims to use natural processes as far as possible, a better understanding of ecological interactions can help to improve its performance (ALTIERI, 2002; SANCHEZ, 1995). The optimisation of natural interactions is especially important in the Amazon, where the access of farmers to external inputs as irrigation and fertilization is often virtually impossible.

To find ways to study ecological interactions in agroforestry, we used Structural Equation Modeling to see how the environment steers seedling performance in multi-species plantations. Here to the environmental influences were divided in four categories: *Resources* (Soil and Litter nutrients); *Conditions* (Above Ground Biomass, Species Richness, Vegetation Cover, Forest Distance and Soil physics); *Competition*, how resource sharing affects plant performance (nearest Next Neighbor and Competition Index) and *Management*, how farmers' management practices affect all previous mentioned influences (Time Since Last Fire, Times Fertilized, Litter Biomass and Shadow Management).

To characterize plant performance the following four traits were used: *Carbon* stock (NAIR et al., 2010) as a measure of the photosynthesis activity by resulting carbon uptake/increment; *Specific Leaf Area* as a trade-off between investing in area for photosynthesis and biomass for leaf resistance, highly correlated with resource availability and environmental conditions (POORTER & BONGERS, 2006); *Absolute Diameter Increment* as a simple measurement of plant growth (FINEGANA, CAMACHOA & ZAMORAB, 1999; GOURLET-FLEURYA & HOULLIERB, 2000) and *Relative Growth Rate*, the growth in time relative to the initial biomass (GRIME & HUNT, 1975), as a measure of the environmental conditions (LAMBERS & POORTER, 1992).

The objective of this work is to evaluate how environmental factors and management of local farmers influence tree seedlings initial performance in different agroforestry plantations. The interpretation of the obtained results aims to provide insights for management optimisation to ensure higher success of agroforestry establishment and provide farmers with more assurance/security. The plantations were sponsored by the *Programa Petrobras Socioambiental* and executed with the assistance of the Non Government Organization *IDESAM*. The involvement of this research started one year after planting.

6.2. Material and Methods

Study area

The study sites are located on the Indigenous Territory Andirá-Marau, Amazonas state, Brazil (Central Amazon). The reserve covers an area of 788,528 hectares, occupied by the Sateré-Mawé indigenous ethnic group. In 2014the reserve was home to around 100 communities and a total of 13,350 inhabitants (LORENZ, 2015).The main income in the area comes from agriculture producing Guaraná (*Paullinia cupana* Kunth), cassava flour (*Manihot esculenta* Crantz), Urucum (*Bixa orellana* L.) and small quantities of other products, as well as the use of non-timber forest products (NTFPs), such as essential oils, natural medicine and honey. The production of Guaraná is following traditional agricultural practices.

The production of cassava is done through shifting cultivation. Stable shifting cultivation systems in tropical rain forest areas need at least a 15-year fallow period to accumulate sufficient fertility for a two-year cropping period (MUTSAERS 1981, cited by van Leeuwen 1992). This means that for every hectare cropped at least another 7.5 hectare of young secondary forest is needed. Over recent years the demand for alternative products the communities produce alongside Guaraná has seen an increase. This has led to a higher interest in agroforestry, alternative management practices and multi-species plantations.

The research sites can be reached by boat from the cities Parintins and Maués (Figure 1), along the rivers Andirá (S 03º15'07'' W 57º06'15.5'') and Marau (S 03º45'24.6'' W 57º16'38.8''), so-called black-water rivers (high concentration of humic acids and a very low nutrient content). The original vegetation is characterized as "terra-firme" (non-flooded, upland) tropical rainforest with a high amount of aboveground biomass and emergent trees (RIBEIRO, 1999; MYSTER, 2017). Between 2014 and 2016 the average annual temperature was around 29ºC and annual precipitation around 2,360 mm (INMET, 2017).

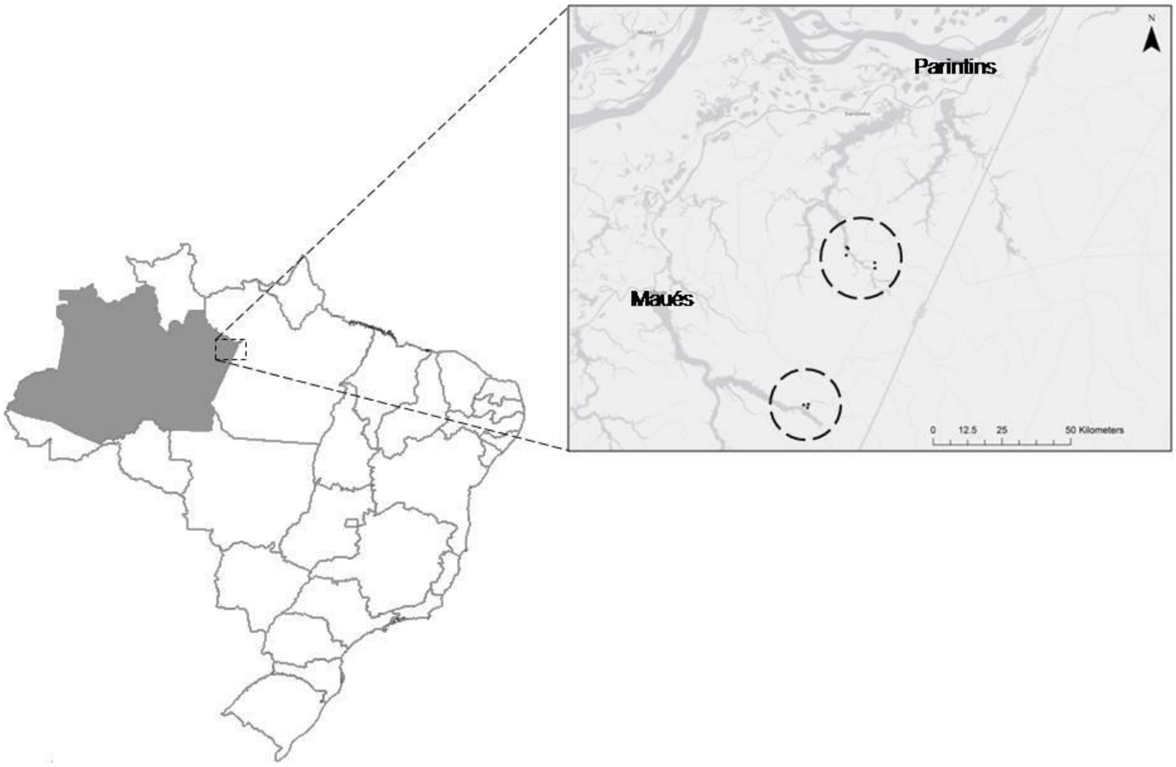

Figure 1. Left: Area showing the location of Amazonas state (dark grey) in Brazil. Right: Research sites (black dots inside dashed circles), along the rivers Marau and Andirá.

The multi-species plantations

The plantations were established in five communities along Andirá river (November 2014) and three along Marau river (February 2015). Locations were selected based on main current vegetation type and are:

Nova Esperança (Secondary forest, 28m x 24m, burnt in 2013, previous 18 years secondary forest, communitary area), Flores (Cassava plantation, 37m x 22m, slash and burn in 2014, previous 40 years secondary forest, private area), Bigode (Cassava plantation, 62m x 12m, slash and burn in 2014, previous 10 years secondary forest, private area), Nova União (Clear cutting, 38m x 15m, open in 2014, private area), Ilha Michiles (Clear cutting, 50m x 50m, cleaned in 2014, previous beans plantation in 2012, communitary area), Vinte Quilos (Clear cutting, private area), Monte Horeb (Guaraná plantation, 50m x 65m, private area) and Castanhal (Urucum plantation, 121m x 28m, previous five times cassava plantation, two years of secondary forest and Urucum with cassava, private area).

Twenty-two different tree species were planted (Table Appendix 1) at an average planting density of 3m x 5m with varying species compositions. A total of 710 tree seedlings were planted in all plantations with an emphasis on avoiding the planting of similar species close to each other to increase diversity. We used the data of the thirteen species present in the sample plots (details on sample are given further on): Graviola (*Annonamuricata*), Peachpalm (*Bactris gasipaes* Kunth), Urucum (*Bixa orellana* L.), Ingá (*Inga edulis* Mart.), Cumaru (*Dipteryx odorata* (Aubl.) Willd.), Tento-Carolina (*Adenanthera pavonina* L.), Pau-Rosa (*Aniba sp*.), Brazilnut (*Bertholletia excelsa* Bonpl.), Acerola (*Malpighia emarginata* DC), Cupuaçu (*Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum.), Andiroba (*Carapa guianensis* Aubl.), Mahogany (*Swietenia sp*.) and Guaraná (*Paullinia cupana* Kunth).

During plantation establishment each planting hole was fertilized with dolomitic limestone (approximate 300g), phosphate (approximate 150g) and laying hen manure (around 4L). The tree seedlings were interplanted (same planting hole) with seeds of Cowpea (*Vigna unguiculata* (L.) Walp.), Maize (*Zea mays* L.), Pigeonpea (*Cajanus cajan* (L.) Millsp.) and Crotalária (*Crotalaria sp.*) and Cassava (*Manihot esculenta* Crantz). As well, in the same alleys, were planted Banana (*Musa sp*.), Sweet Potato, Yam (*Dioscorea sp*.), Passion Fruit (*Passiflora sp.*), Mangarataia (native ginger - *Zingiber sp.*), Pineapple (*Ananas sp.*) and Sugarcane (*Saccharum sp.*), depending on farmers' preferences and local availability of planting material. The more demanding species were only planted in the planting holes of the seedlings, to allow access to the here applied fertilizer. Seedlings were acquired from commercial and communal nurseries, crop seeds from market, crop seedlings from local farmers and maize seeds from Kubeu indigenous ethnic group from the upper Rio Negro. The choice of species, both crops and trees, was done by local farmers based on cultural, economic and environmental importance.

Data collection and processing

At 7 of the 8 locations three sample plots were established and two at one of the 8 locations due to a smaller overall area, leading to a total of 23 plots 10m x 10m in size (containing 215 seedlings at planting and 176 at the final measurement, 26 months later). Plots were randomly distributed over the area to maximize the variability within sites. Data on tree seedling performance, environmental properties, soil, litter and management of the sample plots were collected, as described in detail below and as shown in Table 1. The samples were processed and analyzed at the National Institute for Amazonian Research (*INPA*), Manaus, in the Screening Lab and the Thematic Lab of Soils and Plants.

Table 1. Parameters measured and the time of their measurement in months after plantation establishment.

Variable		Date measured
Plantations	#	Dec/2014 - Jan/2015
Basal diameter	d [cm]	Dec/2015, Aug/2016, Feb/2017
Height	h [m]	Dec/2015, Aug/2016, Feb/2017
Leaf samples	#	Aug/2016
Branch samples	#	Aug/2016
Environmental Properties	#	Aug/2016
Soil	#	Dec/2015
Litter	#	Dec/2015
Questionnaire	#	Aug/2016

<u>Tree seedlings</u>

To assess performance of tree seedlings inside each plot, the following data were collected:

Basal Diameter (d) using a caliper rule and total seedling *Height* (h) with a measuring tape. Branch samples were collected for an average of three branches per seedling. Samples of 2 cm length each were taken close to the main stem (lignified parts) and were then dried for 72 hours at 70 ^{o}C. Branch mass was measured using a scale and volume was measured by water-displacement method (PÉREZ-HARGUINDEGUY et al., 2013). From mass and volume, density was calculated (g cm^{-3}). Organic carbon content (occ) of branches was determined following the Walkley-Black methodology adapted for plant tissue as described by SILVA, 1999. Leaf samples were taken following an approach by PÉREZ-HARGUINDEGUY et al., 2013. An average of five samples of mature leafs were collected per plant. To avoid leaf dehydration, samples were kept in closed plastic bags, inside a bucket with cool water. To assess leaf area using the software *ImageJ* (RASBAND, 2014), leaf samples were put under a piece of glass with a ruler on the side and photographs were taken. To assess leaf dry mass, samples were first dried for 72 hours at 70 ^{o}C and then weighted.

The collected information was used to calculate:

Seedling biomass (b) was calculated using the following equation (paraboloid times branch density), where h = total height, r = basal stem radius = d/2, and branch density = density of sampled branches (average of branch densities by individual).

Equation 1

$$b = Biomass\ [g] = \frac{\pi * r^2 * h}{2} * branch\ density$$

Carbon Stock (CS) was calculated by plant carbon (PC), where b = biomass and occ = organic carbon content of seedlings' branches.

Equation 2

$$PC\ [g] = b * occ$$

and calculating CS for each seedling, as:

Equation 3

$$CS\ [g] = Plant\ Carbon\ final - Plant\ Carbon\ initial$$

Specific Leaf Area (SLA) calculation was based on:

Equation 4

$$\text{SLA}\ \left[\frac{\text{mm2}}{\text{mg}}\right] = \frac{fresh\ leaf\ area}{dry\ leaf\ mass}$$

Absolute Diameter Increment (ADI) following

Equation 5

$$ADI\ \left[\frac{mm}{day}\right] = \frac{d_{final} - d_{initial}}{days\ between\ measurements}$$

Relative Growth Rate (RGR), was calculated using the biomass values as shown in Equation 6

$$RGR \left[\frac{1}{days}\right] = \frac{Lnb_{final} - Lnb_{initial}}{days\ between\ measurements}$$

Lnb is the natural logarithm of biomass b.

Environmental Properties

To assess environmental properties in each plot we determined above ground biomass, vegetation cover, competition index and species richness.

Aboveground biomass (AGB) of additional vegetation on each plot was determined from diameter at breast height (selecting individuals with DBH ≥ 2cm) and total height (using a measurement tape or a clinometer - RÜGNITZ et al., 2009). For the calculations, an allometric equation for secondary "terra firme" forest on central Amazon (NELSON et al., 1999) was used equation 7, where ln = natural logarithm, DBH = diameter at breast height and h = total height.

Equation 7

$$ln(AGB)[\text{Kg}] = -2.5202 + 2.14 * ln(DBH) + 0.4644 * ln(h)$$

The plantwise biomass values were summed up per plot.

As an indirect measure of light availability for the seedlings, *Vegetation Cover* (VC), the percentage of canopy closure of the plots was used. We took photos facing from the ground upwards at16 points in each plot, 0.5 meters above the ground (using a tripod with level bubble), one meter from the plot edges and two meters within points. Photos were analysed using the software *ImageJ* (RASBAND, 2014), with which we calculated the percentage of vegetation pixels for each photo and averaged the 16 photo values, obtaining an average vegetation cover percentage for each plot.

For measuring the competition between the installed seedlings and the surrounding vegetation, the *Competition Index* (COMP_IND) was measured for each seedling inside the plots. The distance between each seedling and the four nearest plants was measured (one in each of the four angles around the seedlings: 0º a 90º, 90º a 180º, 180º a 270º e 270º a 360º). The index was calculated by the nearest plants volume divided by the distance and averaged the four measurements by plant, giving an average size/distance relation of nearest vegetation around the planted seedlings as a competition influence.

As a second estimate for the competition from the surrounding vegetation, the seedling the *Next Neighbors* (NEXT_NGB) was calculated, being the mean of the above-mentioned distances of the four nearest plants to the seedling.

The *Species Richness* (SP_RICH) was measured by the number of plant species (d ≥ 2cm) inside the plots and *Forest Distance* (FD) as the distance between the center of the plots and the nearest forest/vegetation patch.

Soil

Samples were collected at three depths: 0–10cm, 10 – 20cm and 20 – 30cm. Each plot was subdivided in four sub-plots (5m x 5m), where samples were collected on its centers and a composite sample, from the four points, was produced (± 535cm^3) by depth. A 50cm soil profile was dug and on its side a bevelled cylinder (PVC pipe) with a10 cm diameter was introduced with the help of a wooden pole. Samples were collected with a small shovel. For soil density, two of the four sub-plots were selected for sampling (for each depth) and averaging the information per plot. For density sampling we used a bevelled metal cylinder of 5cm and conserved the samples for determining volume and mass in the lab.

Following CLAESSEN et al.(1997), the samples were analyzed with respect to content of Carbon (C, g kg^{-1}), Organic Matter (O.M., g kg^{-1}), Nitrogen (N, g kg^{-1}), Phosphorus (P, mg kg^{-1}), Potassium (K, cmolc kg^{-1}), Calcium (Ca, cmolc kg^{-1}), Magnesium (Mg, cmolc kg^{-1}), Aluminum (Al, cmolc kg^{-1}), Manganese (Mn, mg kg^{-1}), Iron (Fe, mg kg^{-1}), Zinc (Zn, mg kg^{-1}), effective Cation Exchange Capacity (CEC, mmolc dm$^{3-1}$) pH (on water and KCl methods), density (g cm$^{3\ -1}$) and texture (Sand, Silt and Clay percentages).

Litter

In the center of each sub-plot a square of 625 cm^{2}was used for litter sampling. Again, a composite sample from four points in each plot was created. Obtained litter samples were divided into five categories: leaves, branches, green (herbs and grass), charcoal and residue (small indivisible particles). Samples of all 5 categories were analyzed separately following SILVA (2009) for: Biomass (dry weight, g), Water Content (fresh weight - dry weight, converted for ml), Nitrogen (N, g kg^{-1}), Phosphorus (P, mg kg^{-1}), Potassium (K, g kg^{-1}), Calcium (Ca, g kg^{-1}), Magnesium (Mg, g kg^{-1}), Manganese (Mn, mg kg^{-1}), Iron (Fe, mg kg^{-1}) and Zinc (Zn, mg kg^{-1}). For organic Carbon content (occ, g), we mixed all samples of each category together (a composite sample per category). Multiplying by each sample biomass, gave us the organic carbon content related to weight. We used the same methodology for the assessment of organic carbon content of branches.

Management

For accessing the history of use and management carried out by local farmers, information was gathered by questionnaires accomplished with the farmers or their representatives and confirmed by data collected in the field. We could observe a significant relation between: the distance from the seedling until the four *Next Neighbors* (NEXT_NGB) and *Coroamento* (cleaning around seedlings), Time Since Last Fire and *Charcoal Biomass* (CHARCOAL_BIOM), Times Fertilized (number of extra organic fertilizations) and *Litter Biomass* (LITTER_BIOM) and Shadow Management and *Vegetation Cover* (VC). By those findings, we decided to use the measured variables.

6.3. Statistical analysis

STEP 1. For the soil parameters a descriptive analysis was conducted using two-factor analyses of variance; one factor for the three different soil layers (0-10, 10-20 and 20-30 cm depth), the other for the eight areas with plantations. The residual values of each analysis were checked for 'normality' with the Shapiro–Wilk test ($p < 0.05$). When normality was accepted and the F-test gave a significant result ($p < 0.05$), statistically significant differences between the areas were detected with Tukey's range test ($p < 0.05$), while significant differences between the soil layers were found with the Least Significant Difference ($p<0.05$). Variables which didn't show normality were transformed with log (1 + x) to repeat the above given tests.

STEP 2. A descriptive analysis was also conducted for the agroforestry plantations. It was examined: plantation size, ownership, seedlings survival, species composition, spacing, height and biomass. It uses the information obtained in the field visits, summarized in Table 1. The species used in the plantations are briefly described in Table 2. Species composition of the plantations was reviewed. Plantation maps were prepared using the December-2015 measurements. Several seedlings had more than one height and/or stem diameter. For seedlings with more than one height, the highest value was considered. In the case of more than one diameter, the following formula was used: 'single-stem' diameter = square root of the sum of the squared diameters. For seedlings present in February 2017, biomass was calculated for the three measurement dates. For species without density measurements, plant volume was calculated. Only plants with a positive increase in biomass or volume between first and second measurement and between second and third measurement were used to describe height and biomass. Height development of species with five or more plants was graphically presented. For biomass in February 2017 (final measurement), boxplots were prepared to visualize within- and between-species variability.

STEP 3. To consider the variance of species, we used the ANOVAs' residuals from the influence of species on each performance trait as our dependent variable (WHITTAKER, 1984; MAHON, MARTIN & LEMAY, 2008). By this method of "variance partitioning", we excluded the species influence on performance traits, for having a general assumption of influences on plants performance (non-species specific).

STEP 4. For having a general idea of influences on seedlings performance traits (exploratory analysis), we first performed linear regression between each of the four performance traits and each of the 27 influence variables for the seedlings measured in the plots. We used the residuals calculated on step 1.

STEP 5. For getting to know how the joint influences of the variables are influencing the tree seedlings' performance we performed the structural equation modeling (SEM) analysis. We used the residuals from step 1 as a model species independent (13-species Model) and to see how it can be applied in a specie specific perspective, we used the *Carapa guianensis* (Andiroba) data. In this case we didn't use the data per plot, but the data of the entire plantations (81 trees), against the means of the influence variables by area). We chose *Carapa guianensis* for this exercise, as it is the most abundant species in the plantations, for being commonly planted in the Amazon region and for the popular use of its medicinal seed oil.

Structural equation modeling (SEM) is a multivariate statistical technique used to evaluate structural relationships combined with a measurement model, used to test multivariate causal relationships (FAN et al., 2016). SEM allows combining path analysis, factor analysis and multiple regression analysis, and is used to detect structural relationships between measured variables and latent constructs. The latent variables are not directly measured; they are linear functions of a selection of the observed variables (indicators) found by the modelling process of SEM. These functions are built on the shared correlation of the latent variables with the indicators (GRACE, 2006).The following criteria were used to evaluate the fit of the obtained models: the probability of the chi-square goodness of fit test statistic X^2, the comparative fit index CFI and the root mean square error of approximation (RMSEA) (HOOPER, COUGHLAN & MULLEN, 2008). All three criteria range from 0 to 1. Fit was considered sufficient when p (X^2) > 0.05, CFI > 0.90 and RMSEA < 0.05. For considering non-normal data distribution and data skewness in the analysis, the maximum likelihood estimation (MLM) with robust standard errors and a Satorra-Bentler scaled test statistic were used. Once the models had a good fit, we selected the best models based on the highest variance explanation of the performance traits (highest value for R^2) and the significance of the path coefficients (*P* value < 0.05). The path coefficients were reported in standardized (*β*, path coefficients in standard deviation units) and unstandardized (*estimate*) forms. The package *lavaan* (ROSSEEL, 2012) was used for running SEM models and *lavaan.survey* (OBERSKI, 2014) to sampling design specification for running the models. All the models analysed had a good fit, with goodness of fit indices (*p* value for chi-square test, CFI and RMSEA) reported on Table Appendix 2 for the 13-species Model and on Table Appendix 3 for the Andiroba-Model.

STEP 6.We also conducted linear regressions between soil characteristics and litter characteristics (results are reported on Table Appendix 4). Analyses were performed using software *R* version 3.3.3 (R CORE TEAM, 2017) with the package *survey* (LUMLEY, 2004) for sampling design specification.

6.4. Results

Descriptive analysis - Soils

Only the data for Zn didn't show 'normality'; transformation with log (1 + x) solved this. Thirteen of the 16 soil parameters showed statistically significant differences ($p<0.05$) between the soil layers (Table 3, Soil layers). N, K, Organic Matter and percentage of sand showed a significant decrease from 0-10 to 10-20 cm depth and from 10-20 to 20-30 cm, while the percentage clay increased significantly in that direction. In the 0-10 cm soil layer, P, Mg, Ca and C/N were significantly higher than in the two other soil layers, while Fe, Mn and pH-KCl were significantly lower. Al was significantly higher in the 0-10 cm soil layer than in the 20-30 cm layer.

When differences were significant, the curves of the eight areas "followed the trend": showing a higher/lower value in the layers with a significant higher/lower mean value. Of the

136 cases only five exceptions occurred: Al in the areas Castanhal and Nova União, Fe in Monte Horeb, pH-KCl in Castanhal and C/N in Ilha Michiles.

The areas showed statistical differences for N, K, Al, Fe, Zn, Organic Matter, pH-H_20, percentages sand, silt, clay and C/N (Table 3, Areas). Differences in percentages clay and sand were large: from 62.5% clay and 26.1% sand in Monte Horeb to 16.2% clay and 76.7% sand in Castanhal. The differences in percentages clay and sand allowed to form four statistically different groups of areas (Table 2). The only other variable allowing such a partition is Zn: one group only contains Monte Horeb (significantly higher in Zn), the other the remaining seven areas.

Table 2. **Areas grouped by percentages clay and sand.**

	Area[1]			
	Monte Horeb	Bigode Vinte Quilos Flores	Nova União	Nova Esperança Castanhal Ilha Michiles
% Clay	62.5	38.8 – 42.1	31.3	15.8 – 24.1
% Sand	26.1	44.9 - 48.4	54.4	65.5 - 76.7

[1]The four groups of areas corresponding with the columns are significantly different from each other in percentages clay and sand.

Table 3. Mean values of the soil variables per area (left table) and soil layer (right table). The last column of the 'Areas' table and the 4th column of the 'Soil layers' table show the results of the F-test: ns stands for 'not significant; * means significant at p<0.05; ** at p<0.01; * at p<0.001. Values in the same row of a table followed by the same letter are not statistically different (p<0.05).**

	Areas									Soil layers				
Soil variables	Bigode	Castanhal	Flores	Ilha Michiles	Monte Horeb	Nova Esperanca	Nova União	VinteQuilos	F test	0-10 cm	10-20 cm	20-30 cm	F test	Least Sign. Difference
N (g/Kg)	0.79ab	0.58a	1.13c	0.72ab	1.15c	0.79ab	0.74ab	0.94bc	***	1.25a	0.77b	0.55c	***	0.12
P (mg/Kg)	2.52	1.38	2.38	4.11	1.57	1.31	1.32	2.39	ns	4.07a	1.58b	0.71b	***	1.22
K (cmol/Kg)	0.03a	0.037a	0.064b	0.027a	0.049ab	0.038ab	0.045ab	0.049ab	**	0.071a	0.034b	0.022c	***	0.010
Ca (cmol/Kg)	0.11	0.29	0.14	0.15	0.09	0.15	0.20	0.14	ns	0.326a	0.086b	0.065b	***	0.088
Mg (cmol/Kg)	0.07	0.12	0.16	0.07	0.10	0.15	0.17	0.10	ns	0.227a	0.074b	0.053b	***	0.055
Al (cmol/Kg)	0.92ab	0.53a	1.56cd	1.19bcd	1.56cd	1.05abc	0.97ab	1.61d	***	1.32a	1.17ab	1.03b	*	0.21
Fe (mg/Kg)	350ab	357b	244ab	253ab	226a	271ab	282ab	269ab	*	232a	321b	291b	**	49
Zn (mg/Kg)	0.60a	0.44a	0.47a	0.48a	1.31b	0.57a	0.37a	0.73a	***	0.68	0.67	0.52	ns	
Mn (mg/Kg)	1.10	1.94	1.43	0.83	1.41	1.52	2.15	1.38	ns	2.64a	0.93b	0.84b	***	0.77
OM[1] (g/Kg)	16.67a	14.28a	27.84b	19.66ab	25.06ab	20.74ab	15.26a	23.37ab	*	32.6a	16.8b	11.7c	***	4.1
pH_H2O	4.19ab	4.67b	4.29ab	4.29ab	3.97a	4.46ab	4.40ab	4.28ab	**	4.32	4.26	4.37	ns	
pH_KCl	3.98	4.09	3.99	4.10	3.87	4.01	3.99	3.98	ns	3.84a	4.03b	4.13b	***	0.10
Sand (%)	46.32b	76.74e	48.40b	69.29d	26.05a	65.54d	54.38c	44.85b	***	59.2a	52.9b	49.8c	***	1.7
Silt (%)	11.57bc	7.05a	12.81bcd	14.91d	11.42bc	10.36b	14.32cd	14.9d	***	12.42	12.11	11.97	ns	
Clay (%)	42.11d	16.21a	38.78d	15.80a	62.53e	24.10b	31.29c	40.25d	***	28.4a	35.0b	38.2c	***	1.6
C/N[2]	12.24a	14.33abc	14.27abc	15.93c	12.64ab	15.28bc	11.95a	14.53abc	**	15.2a	12.8b	12.3b	***	1.2

[1]OM stands for organic matter. [2]C/N stands for the carbon/nitrogen ratio.

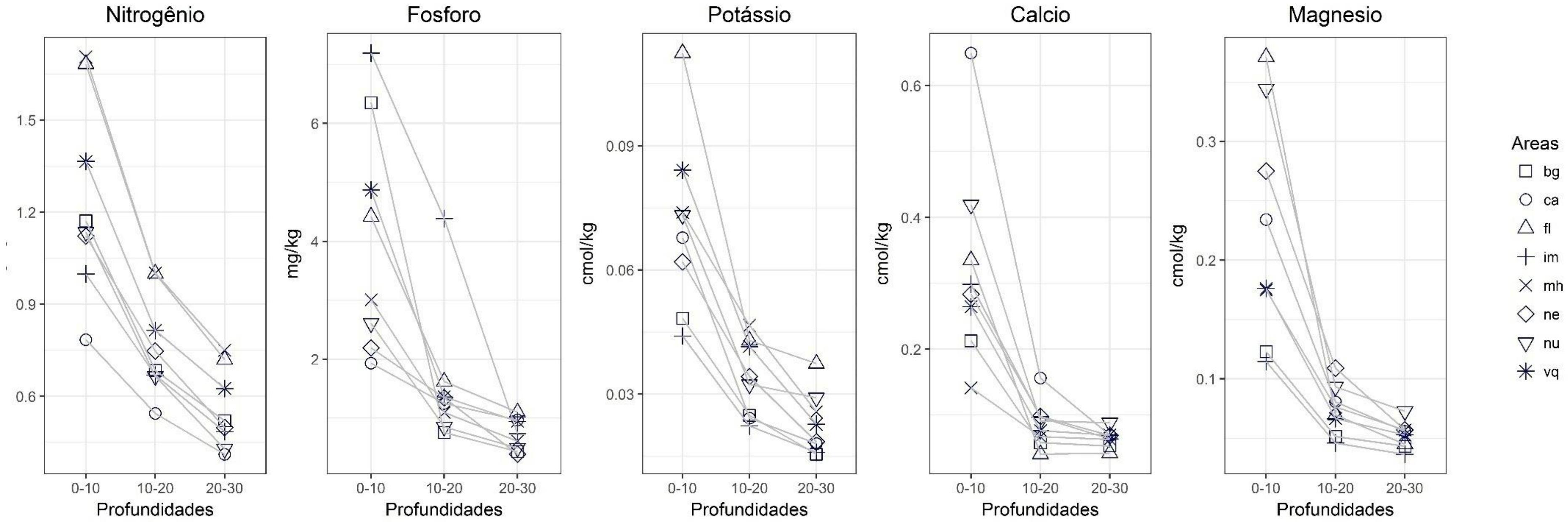

Figure 2a: Relation between nutrient content (N, P, K, Ca, Mg) and soil depth (0-10, 10-20 and 20-30 cm) in eight areas with multi-species plantations. The abbreviation "bg" indicates the area Bigode, "ca" indicates Castanhal, "fl" Flores, "im" Ilha Michiles, "mh" Monte Horeb, "ne" Nova Esperança, "nu" Nova União and "vq" Vinte Quilos.

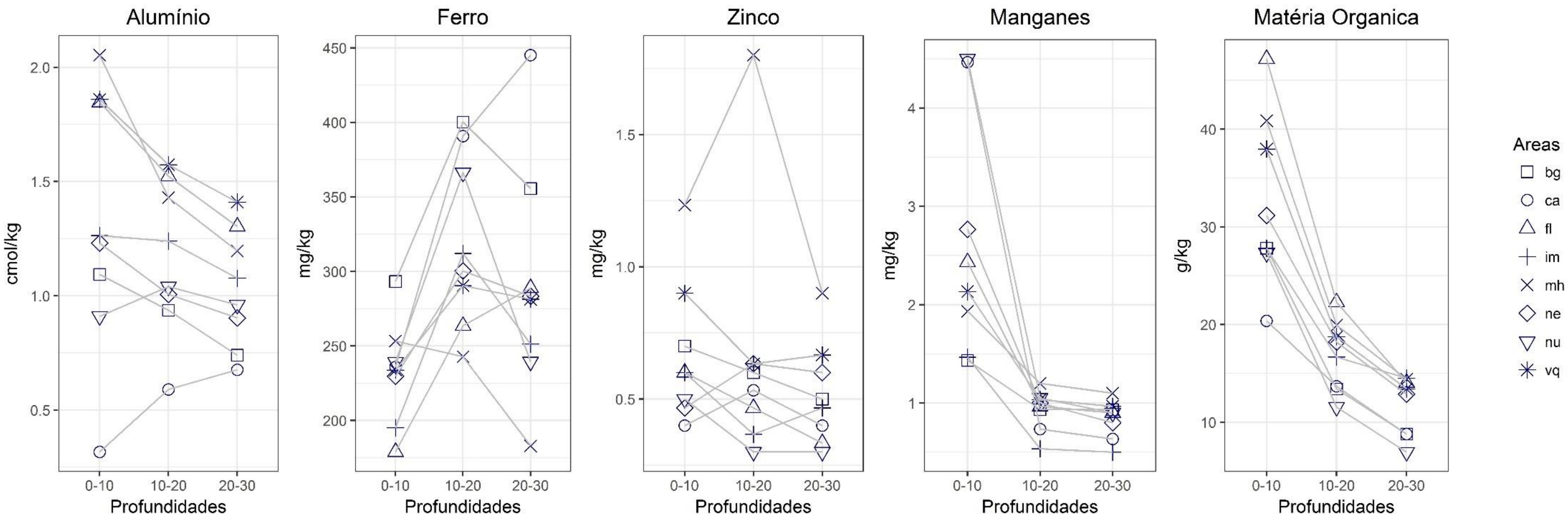

Figure 2b: Relation between nutrient content (Al, Fe, Zn, Mu, Organic Matter) and soil depth (0-10, 10-20 and 20-30 cm) in eight areas with multi-species plantations. The abbreviation "bg" indicates the area Bigode, "ca" indicates Castanhal, "fl" Flores, "im" Ilha Michiles, "mh" Monte Horeb, "ne" Nova Esperança, "nu" Nova União and "vq" Vinte Quilos.

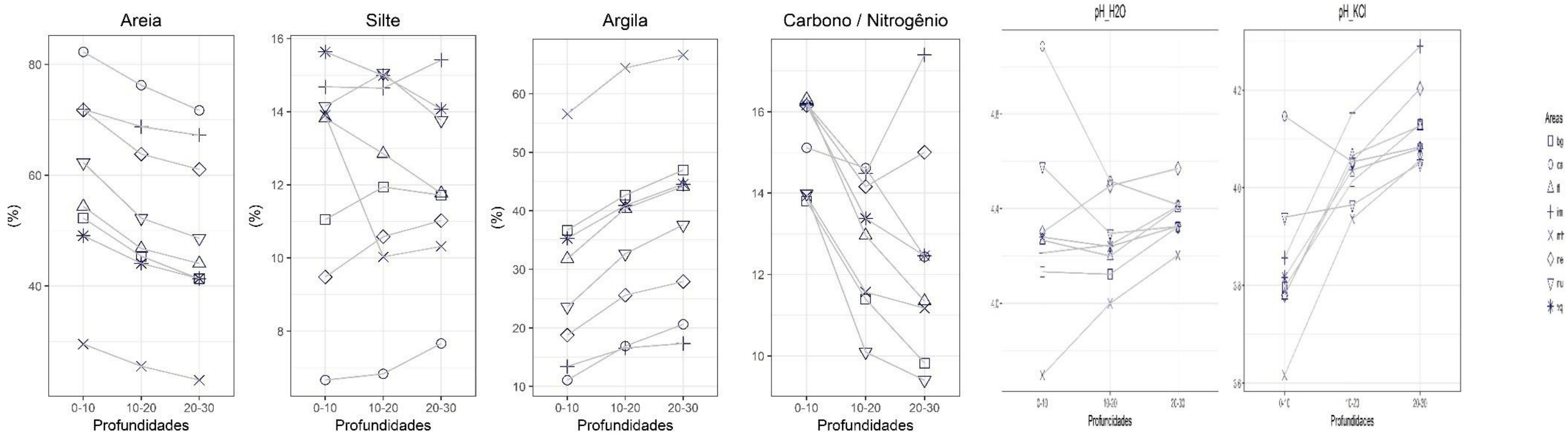

Figure 2c: Relation between soil characteristics (percentages sand, silt, clay, C/N ratio, pH) and soil depth (0-10, 10-20 and 20-30 cm) in eight areas with multi-species plantations. The abbreviation "bg" indicates the area Bigode, "ca" indicates Castanhal, "fl" Flores, "im" Ilha Michiles, "mh" Monte Horeb, "ne" Nova Esperança, "nu" Nova União and "vq" Vinte Quilos.

Descriptive analysis -Plantations

For the data of Table 1, the number of surviving trees per species and plantation was obtained (Table Appendix 3). Per species 1 to 186 seedlings were used. The number of species per plantation varied from 7 to 14 (Table Appendix 2, December 2014). Only Andiroba and Inga occurred in all plantations.

The ‘irregular’ (not rectangular) form of the planted areas (Figures Appendix 1a-1d) shows that the plantations occupied areas available within other forms of land-use. The planted areas varied in size from 52 to 202 planting holes. Using the 3x5 m spacing (not always strictly followed), the six areas on individual farms use 780 to 2190 m^2 (mean 1285m^2). These small areas contrast with the frequently encountered approach of ‘one-hectare a family’, often resulting in too large areas. Small areas make it easier to promote a tradition of tree planting. The two plantations on ‘collective’ land occupy 795 and 3030 m^2. Experience elsewhere in Amazonia indicates that collective tree plantations end up being abandoned (van LEEUWEN 1995).

Many seedlings died, much more than is normal for the early years of a tree plantation. Of the total of 769 nursery plants, planted December 2014, 45% didn’t survive until February 2017 (Table Appendix 2). Mortality in the period December 2014 - December 2015 was 9%, in December 2015 - August 2016 32% and in August 2016 - February 2017 11%. The high mortality in December 2015 - August 2016 is likely due to the low precipitation in rainy season 2015-2016, caused by El Ninõ (with a big drought event). Even giving a ‘discount’ for the El-Ninõ effect, mortality can be considered high. Between the different plantations, mortality varied from 27 to 73%. Mortality of species with more than fifteen planted seedlings is given in Table 4.Very high mortality occurred for Açai (98%), Pau rosa (92%), Itauba (82%) and Cupuaçu (65%). Inga had relative low mortality, 18%.

The maps of the plantations (Figure Appendix 1a-1d) show that overstory species (species of the upper canopy layer of the rainforest as Mahogany) didn’t get the necessary wide spacing, despite its initial phase where spacing is not important yet . These species reach heights of 25 m or more (Table Appendix 1) and need sufficient space to be productive (fruit, timber). In the plantations, overstory trees are often at 3 or 5m distance from each other. In agroforestry systems for Amazonia, Brazilnut, the most important overstory species of the region, gets much larger spacing. MOTA & SOCORRO (1997) mentions a case of 10x20 m, SCHROTH et al. (2015, p.348) 10.3x10.3 m, TREMBLAY et al. (2015, p.196) 10x10 m. Partially, the narrow spacing is due to the high number of overstory trees. With the used 3x5 m spacing, 10x12 m would have been an adequate spacing for overstory trees. With 10x12 m only 12.5% of the planting holes would have been used for overstory trees. But, the plantations have 22-69% overstory trees, much too much. The problem is worsened by the fact that overstory trees are often planted in small groups (clumps), instead of being planted as distant from each other as possible. How to manage a row of four or more overstory trees at 3 or 5-m spacing? Besides, the 3-m spacing in the planting row is also too close for the remaining tree species.

Nevertheless, the accompaniment of the plantations could give important indications for the promotion of tree planting in the reserve. To obtain adequate combinations of species, species characterizations are needed, which focus their possibilities and limitations for agroforestry. As 45% of the installed plants died, a second round of planting will possibly occur to complete the plantations. Before this, a careful mapping of the surviving trees can avoid that replanting repeats the above-mentioned errors.

Considering only seedlings with a positive biomass- or volume-increase, gave a 13.8 % reduction (Table Appendix 4) of the number of plants used for describing height and biomass. Height growth per species is shown in Figure 2. For two species with large within-species differences, two curves are given instead of one. This allows to compare Inga's impressive growth in Flores with that in the remaining areas and Urucum's good growth in Castanhal with its stagnating growth in Ilha Michiles. For Inga, twelve months after planting, the important difference in height already existed (Figure Appendix 2). Comparable strong height growth for Inga was found in an experiment (PENNINGTON 1998, p. 17).

The February-2017, mean biomass of Inga and Andiroba (the most frequent occurring species) was used to illustrate the variability among areas (Figure Appendix 3) (cases of less than five trees per species were not considered). Overall, Inga produced more biomass than Andiroba. As for height, Inga's biomass in Flores was much larger than in the other areas. The difference in biomass is very large: in Flores, Inga had 5 to 23 times more biomass than in the other six areas. For local circumstances, this growth is exceptionally good.

Biomass is shown for species with five or more trees (Orange's biomass isn't given, as its density wasn't measured). As biomass varied very much between the species, two Figures are used. Figure Appendix 4 displays the biomass for eleven species, not presenting Inga.

Figure Appendix 5 exhibits Inga's biomass for seven areas. Inga, Urucum, Andiroba and Graviola showed high variability, while Acerola, Cumaru, Guarana and Mahogany vary much less.

Exploratory Analysis

The specific relations between each variable and each performance trait are shown on Table 1. RGR was positively influenced by FD, Mn, Ca, Mg, and K and negatively by Fe. CARBON had a positive influenced by FD, Charcoal Biomass, Al, Mg, K, C, N, CEC and Next Neighbor and a negative affected of Soil Density and Fe. ADI was positively influenced by FD, Al, Mg, K, C, N, CEC and Next Neighbor and negatively by Soil Density and Fe. SLA was just positive influenced by VC and AGB.

Table 4: Linear regressions between seedlings (n=176) residual performance traits (period 3 and 1) and each influence variable. Positive and negative values are related with slopes signs. P values are reported in parentheses, (*) are significant values (p < 0.05).

	CARBON			**SLA**			**ADI**			**RGR**		
	p	*R^2*	*value*	*p*	*R^2*	*value*	*p*	*R^2*	*value*	*p*	*R^2*	*value*
Forest Distance	**0.000**	0.089	(+)	0.311	0.006	(-)	**0.000**	0.100	(+)	**0.006**	0.047	(+)
Sp Richness	**0.001**	0.070	(-)	0.680	0.001	(+)	**0.000**	0.090	(-)	**0.007**	0.045	(-)
VC	0.254	0.008	(+)	**0.019**	0.034	(+)	0.516	0.003	(+)	0.659	0.001	(+)
AGB	0.388	0.005	(-)	**0.001**	0.062	(+)	0.437	0.004	(-)	0.175	0.012	(+)
Litter Biomass	0.817	0.000	(+)	0.393	0.005	(+)	0.458	0.003	(-)	0.071	0.020	(-)
Charcoal Biomass	**0.002**	0.057	(+)	0.300	0.007	(-)	0.130	0.014	(+)	0.384	0.005	(-)
Soil Density	**0.000**	0.084	(-)	0.746	0.001	(-)	**0.005**	0.049	(-)	0.973	0.000	(-)
Al	**0.000**	0.082	(+)	0.120	0.015	(+)	**0.003**	0.053	(+)	0.536	0.002	(+)
P	0.441	0.004	(+)	0.173	0.012	(+)	0.977	0.000	(+)	0.240	0.009	(-)
Fe	**0.005**	0.048	(-)	0.548	0.002	(+)	**0.001**	0.068	(-)	**0.016**	0.036	(-)
Zn	0.858	0.000	(-)	0.917	0.000	(+)	0.809	0.000	(+)	0.774	0.001	(-)
Mn	0.998	0.000	(+)	0.948	0.000	(+)	0.200	0.010	(+)	**0.009**	0.043	(+)
Ca	0.660	0.001	(-)	0.700	0.001	(+)	0.518	0.003	(+)	**0.006**	0.047	(+)
Mg	**0.008**	0.043	(+)	0.112	0.016	(-)	**0.000**	0.114	(+)	**0.000**	0.094	(+)
K	**0.000**	0.077	(+)	0.357	0.005	(+)	**0.000**	0.096	(+)	**0.002**	0.059	(+)
C	**0.000**	0.122	(+)	0.366	0.005	(+)	**0.000**	0.094	(+)	0.100	0.017	(+)
N	**0.000**	0.113	(+)	0.603	0.002	(+)	**0.000**	0.099	(+)	0.105	0.016	(+)
pH H2O	0.284	0.007	(-)	0.850	0.000	(+)	0.555	0.002	(-)	0.116	0.015	(+)
pH KCl	0.973	0.000	(+)	0.880	0.000	(-)	0.592	0.002	(-)	0.567	0.002	(-)
Sand	0.158	0.012	(-)	0.388	0.005	(-)	0.144	0.013	(-)	0.906	0.000	(-)
Clay	0.258	0.008	(+)	0.510	0.003	(+)	0.193	0.011	(+)	0.820	0.000	(+)
Silt	0.081	0.019	(+)	0.213	0.010	(+)	0.265	0.008	(+)	0.585	0.002	(-)
CEC	**0.004**	0.051	(+)	0.062	0.022	(+)	**0.002**	0.058	(+)	**0.053**	0.023	(+)

CN	0.656	0.001	(+)	0.423	0.004	(+)	0.941	0.000	(+)	0.786	0.000	(+)
Competition Index	0.184	0.011	(+)	0.220	0.009	(+)	0.457	0.003	(+)	0.479	0.003	(+)
Next Neighbor	**0.000**	0.130	(+)	0.195	0.011	(-)	**0.000**	0.101	(+)	0.253	0.008	(+)
Clay/Sand	0.502	0.003	(+)	0.614	0.002	(+)	0.137	0.014	(+)	0.280	0.007	(+)

13-species Model

Models are shown in Figure 2.

The part of the variance explained by CARBON was 14%, with a positive effect of the latent variable Soil (β = 0.25, *estimate*= 479.33, *p* = 0.007), composed by a positive influence of CEC (β = 0.78, *estimate* = 2.45, *p* = 0.001) and C (β = 0.86, *estimate* = 2.24, *p* = 0.000) and a negative influence of Fe (β = -0.64, *estimate* = -35.13, *p* = 0.008). We could see that the joint influence of soil on CARBON was positive, despite the negative influence of Iron, by the higher power of influence of Cation Exchange Capacity and Carbon. The Next Neighbor also had a positive direct influence (β = 0.28, *estimate* = 36.46, *p* = 0.000), meaning that when the distance from seedling to its next neighbours was longer, seedlings accumulated more Carbon, suggesting that the competition by neighbours was less.

Similarly, ADI had 14% of its variance explained by the model, with a positive effect of the latent variable Soil (β= 0.29, *estimate* = 0.01, *p* = 0.003), composed a by a positive influence of CEC (β= 0.78, *estimate* = 2.48, *p* = 0.001) and N (β= 0.68, *estimate* = 0.12, *p* = 0.014), and a negative effect of Fe (β= - 0.64, *estimate* = - 34.85, *p* = 0.013). Next Neighbor had a positive direct effect (β= 0.24, *estimate* = 0.00, *p* = 0.000).

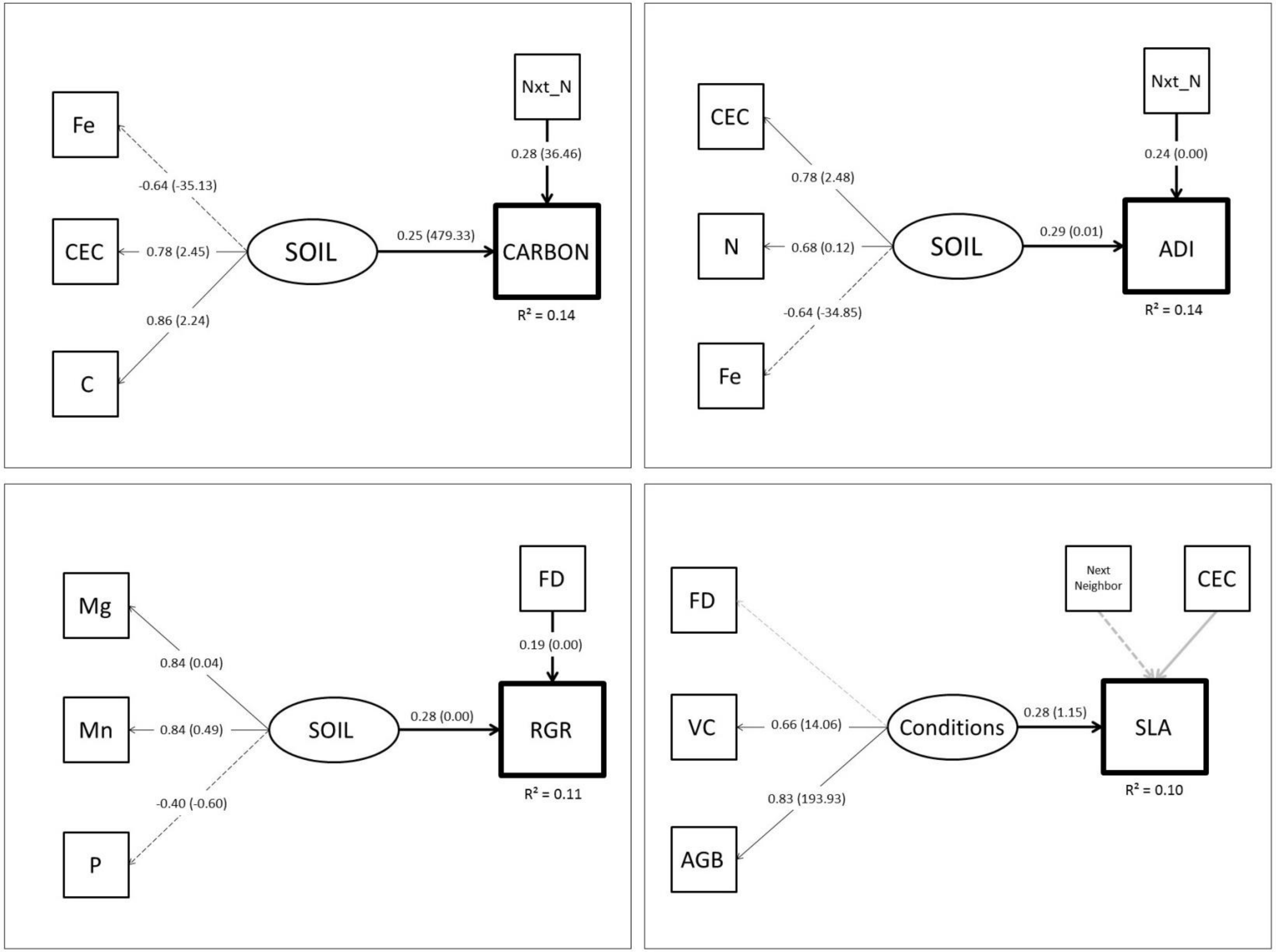

Figure 3. Structural Equation Models for the 13-species-Model).Solid lines are positive influences and dashed lines negative influences. Dark lines are significant paths and clear lines (without values) non-significant paths. Ellipses are latent variables and squares are observed variables. Values are standardized path coefficients and in parenthesis are unstandardized ones.

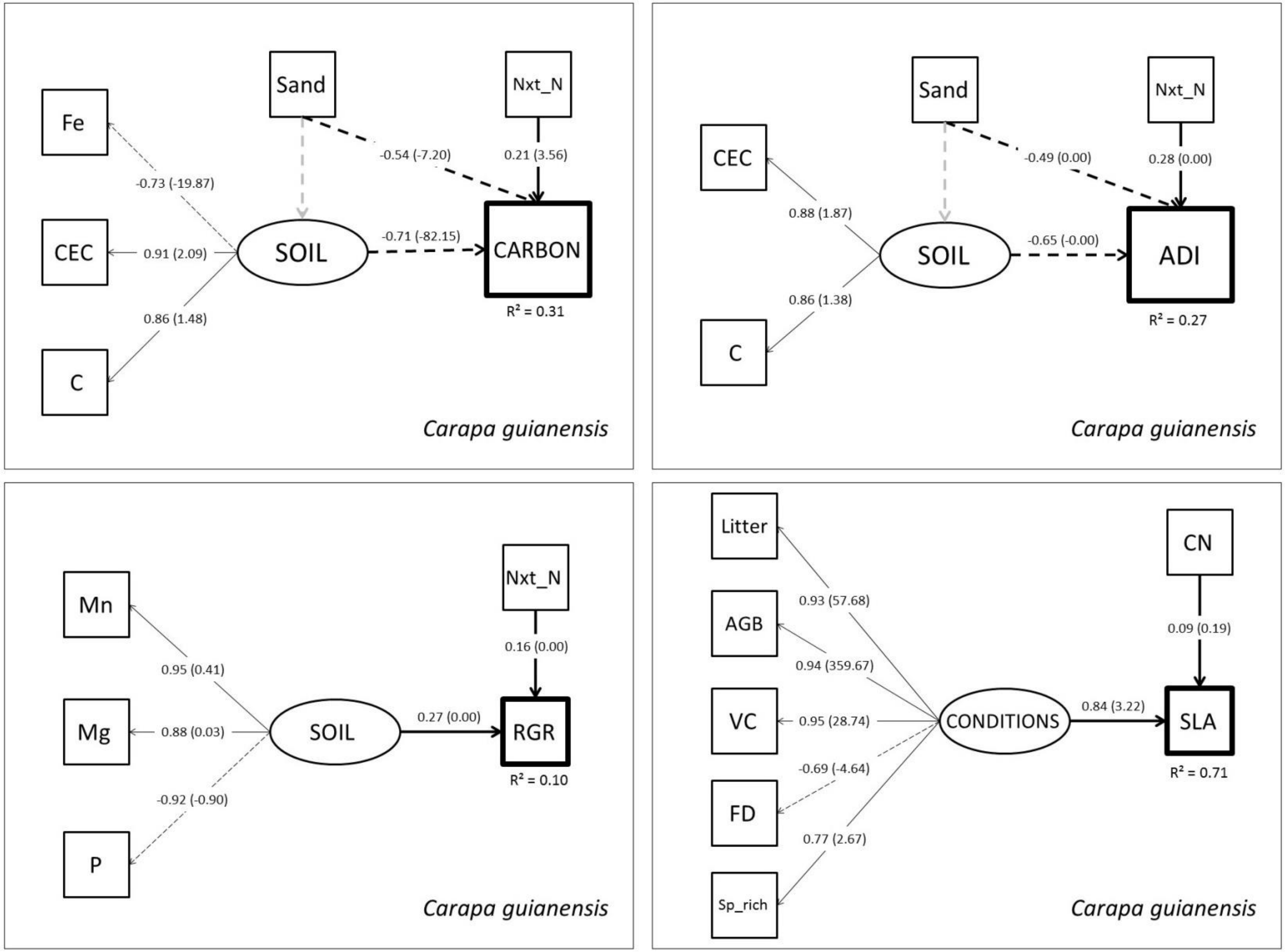

Figure 4. Structural Equation Models for *Carapa guianensis* Model).Solid lines are positive influences and dashed lines negative influences. Dark lines are significant paths and clear lines (without values) non-significant paths. Ellipses are latent variables and squares are observed variables. Values are standardized path coefficients and in parenthesis are unstandardized ones.

RGR had 11% of its variance explained by a positive effect of latent variable Soil (β = 0.28, *estimate* = 0.00, *p* = 0.001), composed by a positive effect of Mg (β = 0.84, *estimate* = 0.04, *p* = 0.000), Mn (β = 0.84, *estimate* = 0.49, *p* = 0.000) and a negative effect of P (β = -0.40, *estimate* = -0.60, *p* = 0.050), where soils with a higher concentration of Magnesium and Manganese and lower concentration of P, gave a higher Relative Growth Rate. Also there was a marginal positive effect of FD (β = 0.19, *estimate* = 0.00, *p* = 0.088), where areas more distant from a forest patches had a better influence on plants RGR.

The SLA had 10% of its variance explained by a marginal positive effect of the latent variable Conditions (β= 0.28, *estimate* = 1.15, *p* = 0.077), composed by a positive influence of VC (β= 0.66, *estimate* = 14.06, *p* = 0.057) and a marginal influence of AGB (β= 0.83, *estimate* = 193.93, *p* = 0.080). Also non-significant, CEC showed a positive direct effect and Next Neighbor a negative effect. These results showed that environmental factors related with light interception (sunlight filtering) had a positive influence on plants' investment in leaf area, instead of investing in leaf mass for resisting harsher environments.

Andiroba-Model

Models are shown on Figure 3.

For *CARBON*, the 31% explained variance was mainly influenced by a negative effect of the latent variable Soil (β = - 0.71, *estimate* = - 82.15, *p* = 0.004), composed by a positive contribution of C (β = 0.86, *estimate* = 1.48, *p* = 0.000), CEC (β = 0.91, *estimate* = 2.09, *p* =), Fe (β = - 0.73, *estimate* = - 19.87, *p* = 0.060). Next Neighbor showed a positive direct effect (β = 0.21, *estimate* = 3.56, *p* = 0.009), which means that increasing the distance between the seedling and the next neighbor would increase the Carbon stock. Sand had a non-significant negative total effect on Soil and a non-significant negative effect on Carbon stock. Because of the negative influence of Sand and Fe on Soil, SOIL had a negative effect on CARBON, despite the positive contribution of C and CEC.

The *ADI* showed a R^2 of 27%, influenced by a negative effect of the latent variable Soil (β = - 0.65, *estimate* = 0.00, *p* = 0.000) composed by C (β = 0.86, *estimate* = 1.38, *p* = 0.001) and CEC (β = 0.88, *estimate* = 1.87, *p* = 0.001), by the negative influence of Sand, that had also a negative direct effect on ADI (β = - 0.49, *estimate* = 0.00, *p* = 0.00). Complementing Next Neighbor had a positive direct effect (β = 0.28, *estimate* = 0.00, *p* =

0.000), meaning that more distant next neighbor and a smaller percentage of sand improves performance.

RGR had a variance explanation of 10%, with a positive influence of the latent variable Soil (β = 0.27, *estimate* = 0.00, p = 0.013), composed by Mn (β = 0.95, *estimate* = 0.41, p = 0.000), Mg (β = 0.88, *estimate* = 0.03, p = 0.000) and P (β = - 0.92, *estimate* = - 0.90, p = 0.000), which shows that soils with high values of magnesium and manganese and low values of phosphorus, jointly, had a good effect on RGR. The Next Neighbor also had a positive effect (β = 0.16, *estimate* = 0.00, p = 0.006), showing that a longer distance from seedling to the next neighbours gives higher RGR values.

SLA had a large part of its variance (71%) explained by the latent variable environmental Conditions (β = 0.84, *estimate* = 3.22, p = 0.000), composed by a positive effect of Litter Biomass (β = 0.93, *estimate* = 57.68, p = 0.000), AGB (β = 0.94, *estimate* = 359.67, p = 0.000), VC (β = 0.95, *estimate* = 28.74, p = 0.000), Species Richness (β = 0.77, *estimate* = 2.67, p = 0.000) and a negative effect of FD (β = - 0.69, *estimate* = - 4.64, p = 0.014). It shows that in environments with a high value of: litter biomass, above ground biomass, percentage of vegetation cover, number of species, and closer to a vegetation patch, seedlings had a better performance (higher values of SLA). This confirms that plants which receive less light form thinner leaves (less risk of drying out).The soil C/N also had positive (but weak) effect (β = 0.09, *estimate* = 0.19, p = 0.054) on SLA.

6.5. Discussion

The high number of species used (22) is a good thing: increasing the experience in the cultivation of different species and contributing to biodiversity maintenance. The more attractive the species are, the more support the plantation will get. For combining the demanding and non-demanding species is problematic. For several species the upland soil of the reserve is too acid and too poor in nutrients. This is especially the case for Orange and Acerola, and, in a lesser degree, for Cacao, Graviola and Peach palm. These species should be grown in the more fertile homegardens (fertilizing and irrigation can also be possible here). A different case is Cashew, a species of Brazil’s semiarid Northeast, which in Amazonia’s humidity is attacked by a fungus, which kills its flowers and young fruits. A densely planted plantation is not the right place for Cashew (van LEEUWEN et al. 1997). To suffer less, Cashew’s broad, umbrella-shaped crown needs to be in the open. This species should only be promoted in special environments (e.g.: sand beaches of black water rivers, open gardens in front of houses). People like to have the above-mentioned, more-demanding species. Planting material of these species (for Cashew, nuts will do) should be distributed to the individual families, together with some advice. Fruits of Cashew and Acerola also are very perishable, a good reason for having them planted by families, close to their houses (as it was observed, quite a few cashew plants on homegardens).

The silvicultural solution is early thinning. This won't work here: farmers will refuse to eliminate trees, which constitute a promise for the future. Peasant farmers don't try to maximize profits, their strategy is 'risk minimization'. They reason as follows. Thinning now means assuming the risk, that, once the harvest is there, some or all trees have disappeared. Taking the risk of having few or no trees at all at harvest, doesn't make sense to them. For this type of agroforestry systems, suitable basic spacing are 5x5, 5.5x5.5 and 6x6 m with 10x10, 11x11 and 12x12 m for the overstory. (The open areas between the seedlings should be used for annual or semi-perennial crops to guarantee the early maintenance of the plantation.)

Soil density is influenced by the management but also by soil texture. Usually, sandy soils have a higher apparent density than clay soils. Also clay soils usually have higher organic matter than sandy soils and so, more CEC (nutrients availability is related with clay and organic matter than density) (Table Appendix 7). Although people think soil fertility is limited by its chemical aspects, soil texture determine soil porosity and water retention capacity. Sandy soils have lower capacity of retaining water, therefore, if there will be an extended dry season, it would have a water shortage for some species. Despite the preferences of certain species for certain soil texture. By the analysis of soil texture, using the Soil Texture Triangle, we could observe four groups by area: Monte Horeb with clay texture; Bigode, Vinte Quilos and Flores with sandy clay texture; Nova União and Nova Esperança a sandy clay loam texture and Castanhal and Ilha Michiles a sandy loam texture. By the chemical point of view, organic matter varies strongly between areas on 0-10cm layer (from 20 to 50g/Kg), decreasing along deep layers. The same pattern can be observed with nitrogen, with reasonable values. Soil acidity is considered high (pH between 4 and 5), but common for tropical soils (specially in the Amazon), and macronutrients (P, K, Ca and Mg) were always low (also common for the Amazon) (MOREIRA & FAGERIA, 2009). Also, high values of Iron and low values of Manganese. Similar results were observed by VIGNOLI et al. (2016) in older agroforestry systems in the same region.

Although considering different species with different ecological strategies together and with high variance among them, controlling the species influence on the general plant analysis (by the variance partitioning method) gave us some interesting information for dealing with multiple species agroforestry systems. When creating a plantation, which combines different species in space (same time period) in the same environmental conditions, our results showed important factors to consider. When considering a plantation of a specific species or when combining species in time (different time period) attention has to be given to the species optimum conditions (VIOLLE et al., 2007). For shade-tolerant species, probably the vegetation cover factor will be more important than for plants without this trait. Selecting the adequate moment to place the species in the system (considering the canopy development) will allow the best development of the seedlings to be introduced.

By searching for the best models with a high power of explanation and significant path coefficients, the results of the 13-species Models and the Andiroba-Models were quite similar. All the variables used in both models had the same type of influence (slope direction and significance) as showed in the explanatory analysis, confirming the generality of the assumptions of the models. There were also interesting differences. For CARBON, ADI and SLA, the Andiroba Model explained a much larger part of the variance (31%, 27%, 71%) than the 13-species model (14%, 14%, 10%), while for RGR, almost equal, small quantities of variance were explained in the 13-species model (10%) and the Andiroba Model (11%).

Interesting outputs from structural equation modeling are the multiple and joint influences of variables. From both models for CARBON and ADI we could observe the positive influence of each soil C and CEC, but by the negative influence of Sand on the Specific Models, the soil influence turned negative. We could confirm by the Sand negative influence on C and CEC availabilities on exploratory analysis (Table 1), where a major influence of Sand (also common negative for all plant traits) turned negative the soil nutrients. Attending to the relations between variables is important for getting to know how the joint influence of factors really acts.

Some soil nutrients played a major role on biomass increment traits (CARBON, ADI and RGR) and environmental conditions related with light interception on the leaf trait SLA. The same result was found by a review of POORTER et al. 2012, where plants total dry matter were highly positive correlated with nutrients and SLA was negatively correlated with irradiance.

Four times out of 6, CEC had a positive effect on the plant performance traits (CARBON, ADI and RGR), three times out of 6 CEC and C were highly correlated, while both showed a significant positive correlation with most other soil nutrients (P, Zn, Mn, Ca, Mg, K and N). This shows the importance of CEC (GOMES & FILIZOLA, 2006) and of soil organic matter for the soil's nutrient storage capacity (ZECH et al., 1997). We found a positive significant influence of soil C on the pH. A higher soil pH means more nutrients are available to plants, important in the Amazon with its very acid soils (MOREIRA & FAGERIA, 2009). The soil pH ranged from 3.67 to 6.45 (average of 4.51), with a positive significant influence on K, Mg, P, Ca, Mn and Zn, meaning that in less acid soils, these nutrients were more available.

It was also stated by LAMBERS & POORTER 1992, that plants growing under low light intensity had higher SLA, with plants allocating biomass from roots and stem to leaves. As specific leaf area is the leaf area per unit of leaf weight, higher values of SLA means a higher plant investment in area than in weight (thinner and broader leaves), with a high photosynthetic rate per unit of leaf dry weight, but less longevity leaves. The environmental factors AGB and FD, related with sunlight duration for seedlings (the shadow created by standing vegetation along the day) and light interception (VC) were correlated with higher values of SLA. On the other hand, AGB and FD had an opposite effect on biomass increment traits (more sunlight availability during the day resulted in a higher biomass increment). Moreover, VC had a positive effect in all plant traits, in which the light intensity filtration from vegetation cover was better than a complete exposure of plants to sun. So, a longer exposure to sunlight with a lower irradiance had a general benefit for seedlings initial performance.

Carapa guianensis

Sand had a negative effect on the plant performance variables CARBON and ADI, while the latent variable Soil had a negative effect on CARBON and the latent variable Soil on ADI. Andiroba showed being not nutrient exigent. COSTA & MORAIS (2013) considered it as very plastic specie. The total negative influence of the Sand content in the soil on ADI and CARBON stock, was confirmed by it better development under clay soils (SOUZA et al., 2006).The environmental conditions Litter Biomass, AGB, VC, FD and Species Richness (characteristics related with sunlight exposure) showed a benefit effect on SLA. Also, the management practice of cleaning around the seedling (correlated with Next Neighbor) had positive effects for different traits, which shows the importance of this management practice for avoiding competition.

6.5.1. Management Implications

Soil

The direct influence of soil nutrients on plant performance showed that Carbon, Nitrogen, Potassium, Magnesium and Cation Exchange Capacity were important for plant performance (Table 4, Figure 2 and 3). The management practice of covering the soil with organic matter (mulching) is an important practice by it capacity of retaining nutrients, mainly in sandy soils. The pH showed to be an important factor, as mentioned before, the soil carbon influence on pH and the organic matter play an important role in decreasing soil acidity.

Soil density was strongly negative correlated with nutrients availability, with significant effect in seven nutrients (Table Appendix 4) and a negative effect in the performance traits CARBON and ADI (Table 1). This shows the importance of soil density on the performance of the tree species.

Environmental Properties

For the establishment of seedling after planting, Vegetation Cover (by its shadow) is known as an important factor for reducing evapotranspiration, decreasing temperature and reducing the intensity of sunlight (which can dry the leaves). During the development of the plantations, trees can be pruned to give more (sun) light to the lower plant strata. It is important to consider the light demand of each species in the plantations, choosing where and when the species that will enter later on will be planted. In this way the different strata can be carefully designed during the development of the plantation, finding the best conditions for each species and the best possible interactions between the different species composing the system. VC was positively correlated with litter biomass, which suggests the importance of the vegetation cover for litter input on the system. Selecting multi-purpose species with high leaves and branches production and with high nutrient content (especially those nutrients mentioned above), as “litter producers”, is an interesting practice for constant biomass deposition (and mulch production) in the soil.

The practice of cleaning around the seedling (Next Neighbor) for avoiding competition showed to be a good practice. If the idea of the system is to consort species it is important to choose species that do not occupy the same soil layer or carry the plantation considering certain space to avoid species competition.

Plantations

Installing and accompanying tree plantations in villages of an Amazonian indigenous reserve is difficult and labor-intensive, because of the complicated, time-consuming logistics (distances, communication). The here described work furnishes important indications for tree-planting promotion under these circumstances.

Mortality was high, even giving a 'discount' for the extra mortality caused by El Niño. Inga combined lowest mortality with best growth. The high number of species used (22) is very positive, but the choice of the species can be improved. In future work, the following aspects need to be avoided: (1) too close spacing; (2) overstory trees without the necessary large spacing; (3) too large percentage of overstory trees; (4) overstory trees badly distributed; (5) partially inadequate species' choice.

1. Three meters distance in the row is too close for this form of agroforestry. A 5x5 to 6x6 m basic spacing is recommended, instead of the now used 3x5 m.
2. Overstory trees didn't get the corresponding large spacing (see 3 and 4). Thinning can't solve this, as the peasant farmers of the reserve will refuse to eliminate trees.
3. The percentage overstory-trees is too high: with 3x5 m spacing, 10x12 m is an adequate spacing for overstory trees (space needed for these large trees to be productive), occupying only 12.5% of the planting places. The plantations have 22-69% overstory trees.
4. Overstory trees are planted in small groups (clumps), instead of as distant from each other as possible.
5. The species choice included species as Orange and Acerola, which need better soil and more intensive management, while Cashew doesn't do well in a closed tree plantation.

As people like to have these more demanding species, they can be included in a component of future planting programs, which distributes planting material to the families.

To prepare an adequate species mix: species descriptions are needed, which focus their use in agroforestry (spacing, environmental needs).Future tree-planting campaigns need:

(1) improved plantation design; (2) good-quality planting material of a well-chosen species mix. This is only possible in projects of sufficient-long duration. Before planting can occur, many things must be done: villages visited to identify potential areas for planting and interest in species; seed trees identified, seed collected, when the season is there; planting material produced.

6.6. Conclusion

In conclusion, quality of soil (C, N, K, Mg, CEC, pH, texture and density), Litter Biomass, Vegetation Cover, and Next Neighbor had major influence on seedlings initial performance on the different agroforestry systems. Considering those factors when managing the plantations would increase the success rate of plants. Also practices as: spacing among certain species (considering the pioneers, secondary, etc.), choosing better genetic material for seedlings production (collecting local seeds), choosing better areas for plantations (considering the factors above mentioned), are important for a better development of agroforestry systems in the region.

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6.9. Appendix

Table Appendix 1. Species used in the multi-species tree plantations.

Local and (English) name	Use	Height (m)	Scientific Name	Family
	PALMS			
Pupunha (Peachpalm)	Fruit	15a*	*Bactris gasipaes* Kunth	Arecaceae
Patauá	Fruit	15-25f	*Oenocarpus bataua* Mart.	Arecaceae
Açaí	Fruit, (Seed for handicraft)	20b	*Euterpe sp.*	Arecaceae
	SHRUBS, SMALL-TREES			
Guaraná	Seed (stimulating beverage)	4	*Paullinia cupana* var. *sorbilis*	Sapindaceae
Graviola	Fruit	4-8a	*Annona sp.*	Annonaceae
Laranja (Orange)	Fruit	4-6	*Citrus* L.	Rutaceae
Urucum	Seed (condiment, food coloring)	6b	*Bixa orellana* L.	Bixaceae
Acerola	Fruit	2-6a	*Malpighia emarginata* DC	Malpighiaceae
Cacau	Seed, (Fruit pulp)	10e	*Theobroma cacao* L.	Malvaceae
Cajueiro (Cashew)	Nut, Fruit	3-8a	*Anacardium occidentale*	Anacardiaceae
	MEDIUM-SIZED TREES			
Cupuaçu	Fruit pulp, (Seed)	6-18e	*Theobroma grandiflorum* (Willd. ex Spreng.) K.Schum.	Malvaceae
Tento-Carolina	Seed (handicraft)	15b	*Adenanthera pavonina* L.	Fabaceae
Ingá	Fruit, Fertilizer (prunings)	10-15a	*Inga edulis* Mart.	Fabaceae
	UPPER-LAYER AND EMERGENT TREES			
Cumaru	Seed (Coumarin), Timber	30d	*Dipteryx odorata* (Aubl.) Willd.	Fabaceae
Itaúba	Timber	20-40c	*Mezilaurus itauba* (Meisn.) Taub. ex Mez	Lauraceae
Mogno (Mahogany)	Timber	25-30c	*Swietenia sp.*	Meliaceae
Pau-Rosa	Rosewood oil (prunings, timber)	20-25c	*Aniba sp.*	Lauraceae
Jatobá	Timber, Fruit	30-40a	*Hymenaea courbaril* L.	Fabaceae
Castanha (Brazilnut)	Nut, Timber	40-50a	*Bertholletia excelsa* Bonpl.	Lecythidaceae
Andiroba	Seed (medicinal oil), Timber	20-30c	*Carapa guianensis* Aubl.	Meliaceae

*a: Cavalcante1988; b: Wikipédia (10/01/2018); c: Lorenzi 1998; d: Loureiro et al. 1979; e: FAO 1987; f: Clay et al. 1999.

Observation: Originally 22 tree species were planted, instead of the 20 mentioned in this list. The two not-mentioned species are Caramuri and Catauari, of each only one seedling was planted. Both seedlings died before the first measurement, 12 months after planting.

Table Appendix 2. Number of trees per species and area from December 2014 till February 2017.

Áreas*: Species	December 2014 (planting)									December 2015								
	bg	ca	fl	im	mh	ne	nu	vq	T**	bg	ca	fl	im	mh	ne	nu	vq	T
Acai	2	4	2	9	16	1	7		41	1	3	2	8	16	1	6		37
Acerola	8	7	4				9	28	56	8	7	4				9	28	56
Andiroba	9	48	7	35	2	5	12	50	168	9	48	7	33	2	5	12	50	166
Cacau				1					1				1					1
Cashew	1	1	1						3	1	1	1						3
Brazilnut				15	5	2			22				15	5	2			22
Cumaru				19	3	5			27				18	3	5			26
Cupuaçu	5	3					8	1	17	5	3					8	1	17
Graviola		1	4	7				40	52		1	4	7				40	52
Guarana			9					24	33			9					24	33
Inga	35	11	19	68	18	22	10	3	186	35	11	19	65	18	22	10	3	183
Itauba				12		5			17				10		5			15
Jatoba					1				1					1				1
Orange				5	1				6				5	1				6
Mahogany	3	22	4						29	3	21	4						28
Pataua				3					3				3					3
Pau rosa	6				4	10	4		24	6				4	9	4		23
Peachpalm				12	1				13				12	1				13
Tento				6					6				6					6
Urucum		4		3					7		4		3					7
Mortos	3	23	6	7	1	3	14	0	57									
Total plants	72	124	56	202	52	53	64	146	769	68	99	50	186	51	49	49	146	698
Total species	9	10	9	14	10	8	7	7	22	8	9	8	13	9	7	6	6	20

	August 2016									February 2017								
Acai			1	1	1				3			1						1
Acerola	4	4	2				6	24	40	2	3	2				6	23	36
Andiroba	5	12	6	17	1	1	11	37	90	5	9	6	16	1	1	11	33	82
Cacau				1					1				1					1
Cashew	1	1	1						3	1		1						2
Brazilnut				12	4	2			18				9	4	2			15
Cumaru				13	2	5			20				11	1	4			16
Cupuaçu	2						5	1	8	1						5		6
Graviola			3	4				32	39			2	4				32	38
Guarana			8					18	26			5					11	16
Inga	30	9	18	63	10	22	9	3	164	29	8	17	60	8	21	8	1	152
Itauba				4					4				3					3
Jatoba					1				1									
Orange				5	1				6				5	1				6
Mahogany	3	17	4						24	3	14	4						21
Pataua				2					2									
Pau rosa	2								2	2								2
Peachpalm				12					12				12					12
Tento				5					5				5					5
Urucum		4		3					7		4		3					7

Total plants	47	47	43	142	20	30	31	115	475		43	38	38	129	15	28	30	100	421
Total species	7	6	8	13	7	4	4	6	20		7	5	8	11	5	4	4	5	18

*For area names see Table 5. **T=Total of plants per species.

Table Appendix 3. Mortality in the first 26 months

Species	Number of seedlings	
	Planted	Mortality
Açai	41	98%
Acerola	56	36%
Andiroba	168	51%
Brazilnut	22	32%
Cumaru	27	41%
Cupuacu	17	65%
Graviola	52	27%
Guarana	33	52%
Inga	186	18%
Itauba	17	82%
Mahogany	29	28%
Pau rosa	24	92%

Table Appendix 4. Trees used in describing height and biomass. These trees increased in biomass/volume in Dec15-Aug16 and Aug16-Fev17.

	Areas								
Species	Bigode (bg)	Castanha (ca)	Flores (fl)	Ilha Michiles (im)	Monte Horeb (mh)	Nova Esperanca (ne)	Nova Uniao (nu)	Vinte Quilos (vq)	TOTAL
Acai			1						1
Acerola	1	1	1				5	15	23
Andiroba	5	8	6	16	1	1	11	31	79
Brazilnut				4	4	1			9
Cacau				1					1
Cashew	1								1
Cumaru				11	1	4			16
Cupuacu	1						5		6
Graviola			1	3				26	30
Guarana			4					10	14
Inga	25	8	16	55	6	17	8	1	136
Itauba				3					3
Mogno	3	14	4						21
Orange			4	1					5
Pau rosa	1								1
Pupunha				5					5
Tento				5					5
Urucum		4		3					7
Number of plants	37	35	37	107	12	23	29	83	363
Number of species	7	5	8	11	4	4	4	5	18

Ilha Michiles (im)

1[1]	2	3	4	5	6	7	8	9	10	11	12
andiroba	castanha	andiroba	graviola	cumaru	inga	inga	inga	andiroba	castanha	andiroba	tento
inga	pupunha	graviola	inga	inga	cumaru	inga	castanha	acai	inga	cumaru	acai
pupunha	inga	graviola	andiroba	acai	inga	cumaru	andiroba	cumaru	acai	pupunha	cumaru
inga	inga	itauba	inga	inga	andiroba	inga	inga	andiroba	andiroba	morto	itauba
andiroba	andiroba	inga	inga	andiroba	castanha	cumaru	itauba	inga	urucum	andiroba	inga
inga	castanha	graviola	inga	inga	morto	inga	inga	cumaru	tento	inga	itauba
pupunha	andiroba	inga	cumaru	morto	morto	inga	andiroba	itauba	acai	cumaru	inga
inga	andiroba	itauba	inga	inga	castanha	castanha	inga	andiroba	inga	laranja	andiroba
pataua	pupunha	inga	itauba	cumaru	graviola	andiroba	cumaru	inga	andiroba	andiroba	cumaru
pataua	pupunha	andiroba	inga	acai	acai	cumaru	castanha	cumaru	tento	tento	andiroba
cacau	itauba	laranja	inga	cumaru	morto	inga	inga	inga	inga	inga	acai
pataua	inga	inga	castanha	inga	inga	castanha	castanha	andiroba	andiroba	tento	andiroba
inga	pupunha	pupunha	inga	andiroba	cumaru	inga	inga	castanha	pupunha	inga	pupunha
graviola	inga	inga	andiroba	pupunha	inga	andiroba	cumaru	cumaru	tento	andiroba	urucum
laranja	laranja	inga	inga	inga	pupunha	castanha	itauba	itauba	inga	acai	
		graviola	inga	itauba	andiroba		inga	inga	andiroba		
		laranja	inga	andiroba	inga			castanha	urucum		
			itauba	inga	andiroba						
			inga	morto	inga						
			morto	castanha							
			inga								
			andiroba								

Bigode (bg)

1	2	3
inga	inga	inga
inga	mamao	inga
inga	cupuacu	andiroba
inga	inga	acerola
mogno	inga	andiroba
mogno	inga	mogno
paurosa	acerola	inga
acai	caju	
morto	inga	inga
cupuacu	inga	andiroba
andiroba	acai	inga
inga	inga	inga
cupuacu	inga	inga
inga	inga	acerola
inga	inga	inga
cupuacu	inga	inga
andiroba	andiroba	acerola
paurosa	acerola	acerola
andiroba	acerola	
andiroba	inga	
andiroba	inga	
	cupuacu	
	inga	
	inga	
	inga	
	acerola	

Flores (fl)

1	2	3	4	5	6
guarana	inga	guarana	inga	mogno	andiroba
andiroba	guarana	inga	graviola	graviola	andiroba
mogno	morto	guarana	inga	acai	andiroba
inga	morto	inga	inga	inga	andiroba
morto	inga	guarana	mogno	acerola	andiroba
morto	inga	inga	morto	inga	andiroba
graviola	guarana	guarana	morto	mogno	
guarana	inga	inga	inga	acerola	
guarana		inga	graviola	inga	
		inga		acai	
				caju	
				inga	
				graviola	

Figure Appendix 1a. Map of the plantations Ilha Michiles (im), Bigode (bg) and Flores (fl). Overstory species marked yellow.

[1]Numbers correspond to planting rows. Spacing: 3 m in the row, 5 m between rows

Castanhal (ca)

1[2]	2	3	4
acerola	andiroba	acerola	andiroba
mogno	andiroba	andiroba	andiroba
cupuacu	andiroba	andiroba	acai
mogno	morreu	andiroba	inga
caju	morreu	andiroba	andiroba
inga	andiroba	andiroba	acerola
andiroba	acerola	morreu	inga
andiroba	andiroba	andiroba	catauari
andiroba	morreu	morreu	acerola
morto	morreu	andiroba	andiroba
morto	andiroba	andiroba	acerola
graviola	andiroba	andiroba	inga
andiroba	andiroba	acerola	andiroba
andiroba	andiroba	andiroba	morreu
acai	andiroba	andiroba	acai
andiroba	andiroba	urucum	cupuacu
andiroba	andiroba	andiroba	andiroba
mogno	morreu	inga	morreu
mogno	andiroba	cupuacu	andiroba
mogno/andiroba	andiroba	morreu	andiroba
acai	morto	morreu	andiroba
andiroba	morto	morreu	andiroba
andiroba/mogno	morto	morreu	andiroba
mogno	andiroba	andiroba	andiroba
andiroba	andiroba	urucum	
mogno	morreu	urucum	
mogno	morreu	inga	
mogno	andiroba	andiroba	
	inga	andiroba	
	andiroba	morreu	
	inga	andiroba	
	andiroba	andiroba	
	inga	andiroba	
	inga	urucum	
	inga		
	andiroba		
	andiroba		

Nova Esperança (ne)

1	2	3	4	5	6	7
pau rosa	andiroba	morto	Itauba	itauba	cumaru	andiroba
inga	inga	inga	inga	inga	inga	inga
itauba	itauba	pau rosa	pau rosa	andiroba	acai	pau rosa
inga	inga	inga	inga	inga	inga	inga
andiroba	itauba	pau rosa	cumaru	morto	pau rosa	andiroba
inga	inga	inga	inga	inga	inga	inga
cumaru	pau rosa	pau rosa	pau rosa	pau rosa	morto	castanha
	cumaru	inga	castanha		cumaru	

Nova União (nu)

1	2	3	4	5
morreu	acerola	acerola	andiroba	andiroba
morreu	paurosa	paurosa	inga	acai
morreu	acerola	acerola	acai	morreu
morreu	acai	morreu	cupuacu	morreu
andiroba	inga	morreu	inga	inga
paurosa	andiroba	morreu	cupuacu	andiroba
acerola	cupuacu	inga	inga	acai
morreu	cupuacu	andiroba	andiroba	andiroba
paurosa	acai	acai	inga	morreu
andiroba	andiroba	acerola	cupuacu	morreu
cupuacu	acai	cupuacu	inga	acerola
	andiroba	morreu	cupuacu	andiroba
		andiroba	acerola	inga
		morreu	acerola	inga

Figure Appendix 1b. Map of the plantations Castanhal (ca), Nova Esperança (ne) and Nova União (nu).Overstory species marked yellow.

[2]Numbers correspond to planting rows. Spacing: 3 m in the row, 5 m between rows.

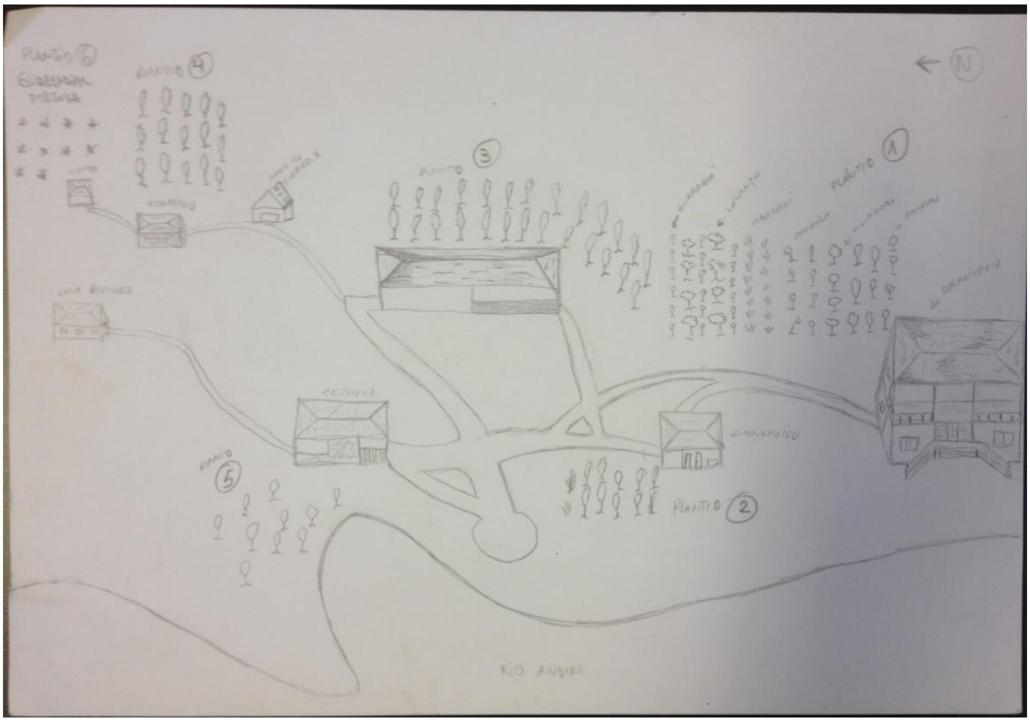

Figure Appendix 1c. Map of the plantation Vinte Quilos (vq).

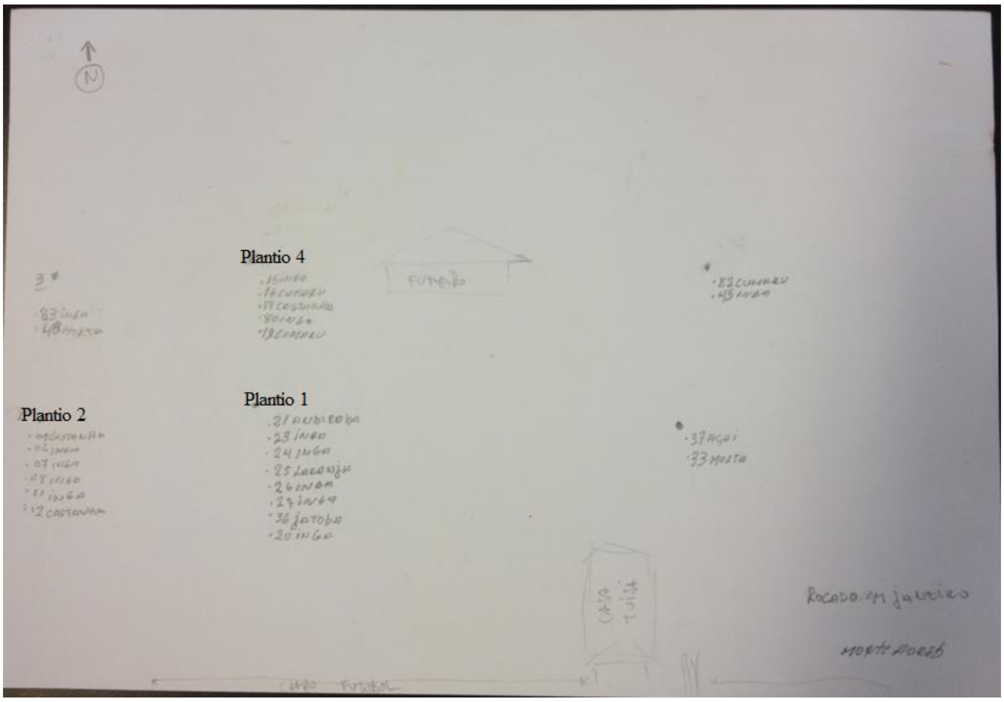

Figure Appendix 1d. Map of the plantation Monte Horeb (mh).

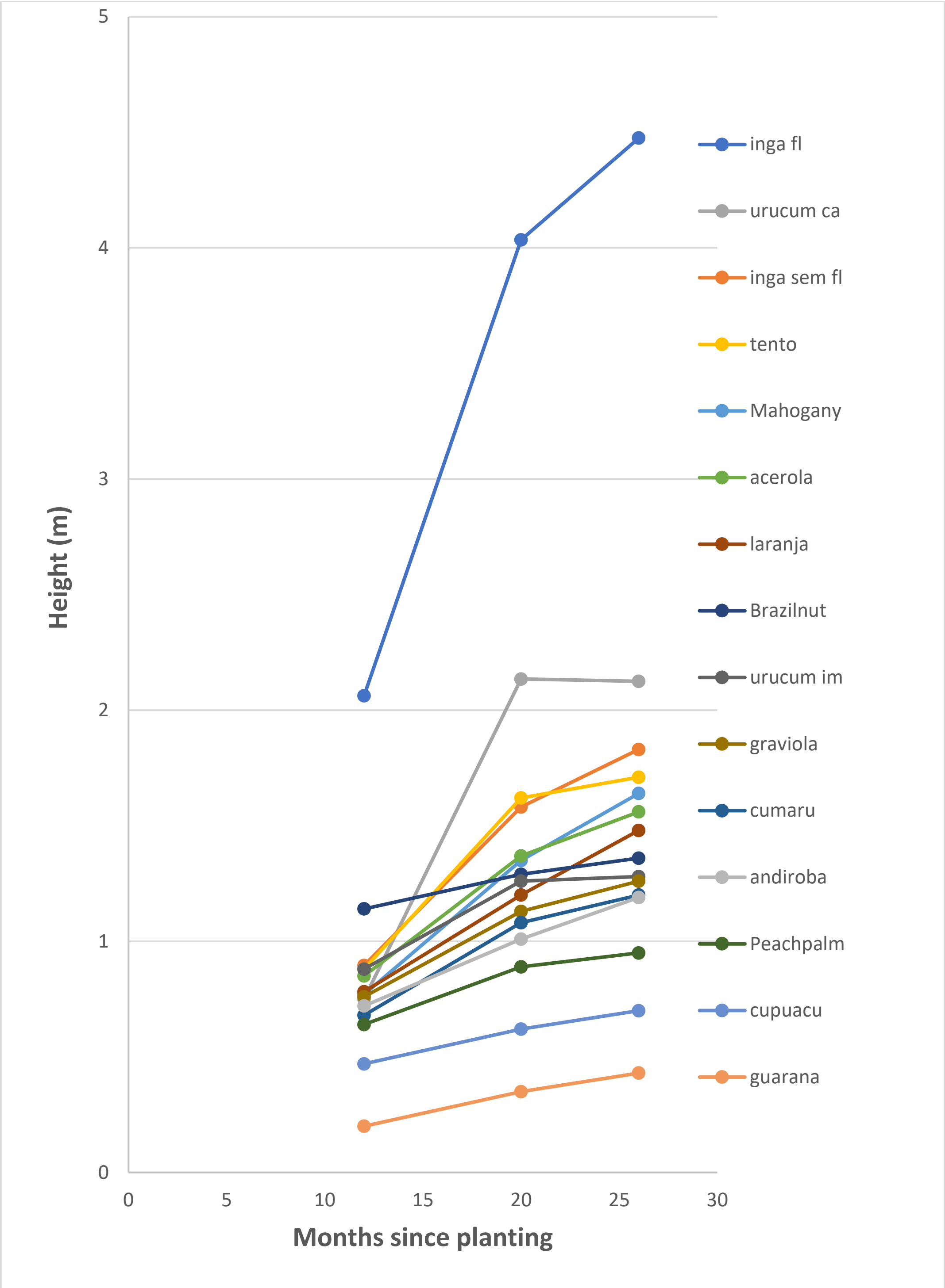

Figure Appendix 2. Mean height per species 12, 20 and 26 months after planting. Inga is separated in Flores and other areas, Urucum in Castanhal (strong growth) and Ilha Michiles (stagnated growth).The species names are ordered according to the height at 26 months.

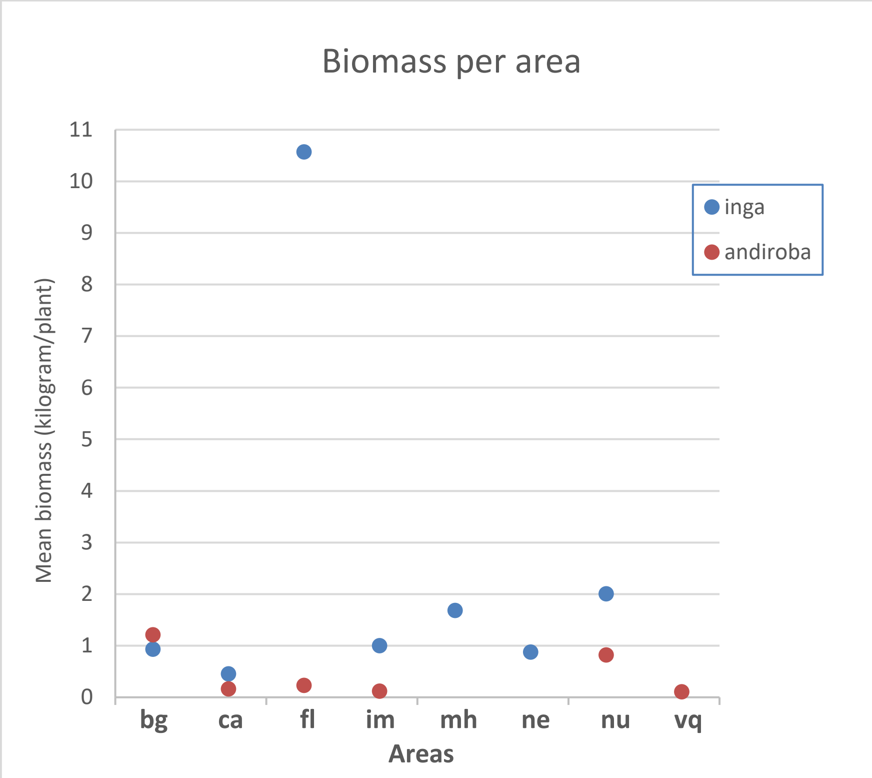

Figure Appendix 3. Mean biomass (kg/plant/area) of Inga and Andiroba after 26 months. Inga produces more biomass in four of the five areas with both species, while in the fifth area Bigode (bg) the difference is very small. In Flores (fl), Inga produces much more biomass than in the other six areas.

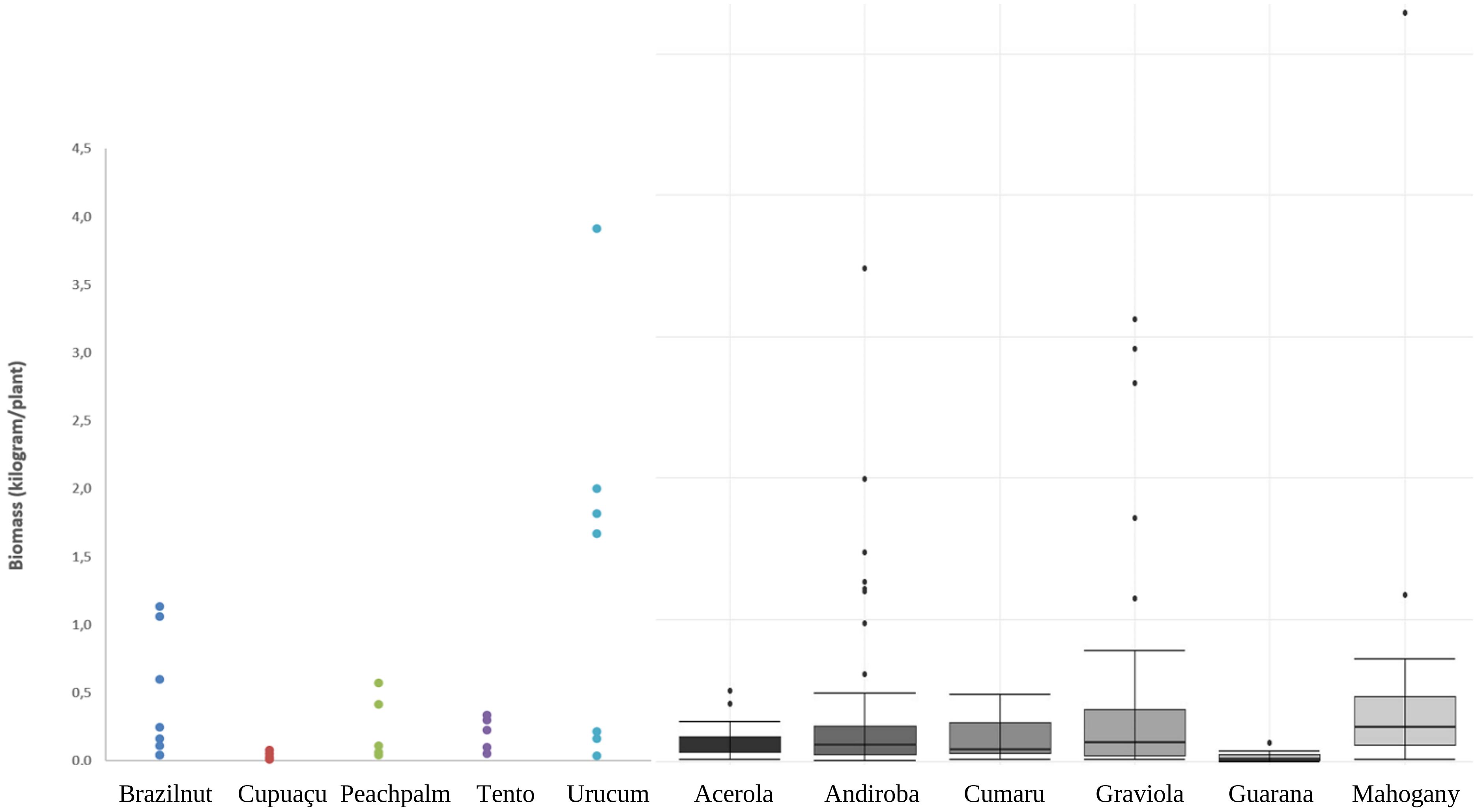

Figure Appendix 4. Biomass per tree in February 2017. Left: simplified presentation. Right: 'full' boxplots. The simplified presentation is used as it is more informative (and possible) for the species with few (5-9) individuals.

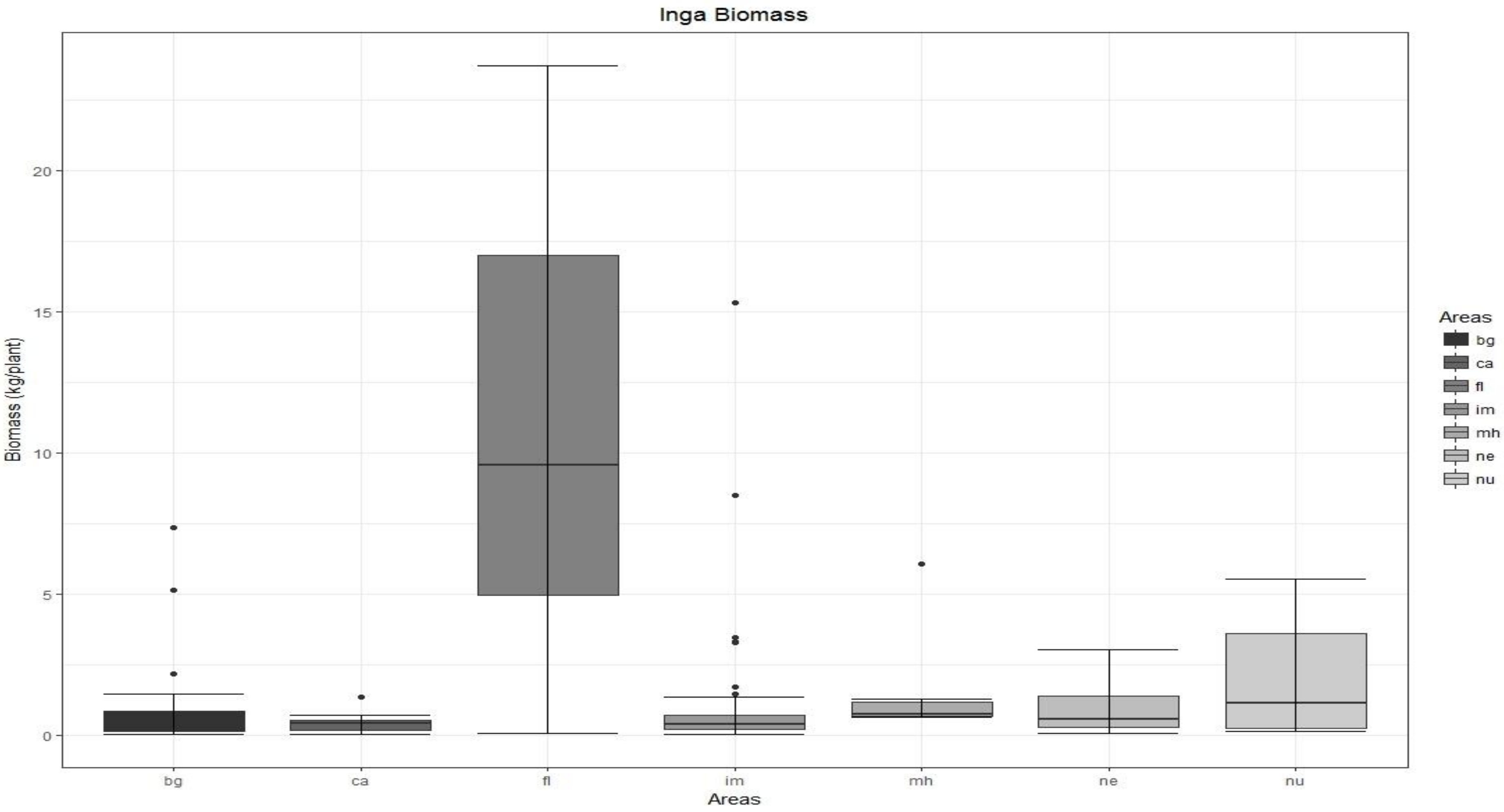

Figure Appendix 5. Boxplots of Inga in the areas with 6 or more Inga trees.

Table Appendix 5. General Models fit values for each performance trait.

	X^2 (*p*)	CFI	RMSEA
General Models			
CARBON	0.690	1.000	0.000
ADI	0.729	1.000	0.000
RGR	0.830	1.000	0.000
SLA	0.884	1.000	0.000

Table Appendix 6. Specific Model fit values for each performance trait.

	X^2 (*p*)	CFI	RMSEA
Carapa guianensis			
CARBON	0.579	1.000	0.000
ADI	0.772	1.000	0.000
RGR	0.187	0.908	0.055
SLA	0.452	1.000	0.000

Table Appendix 7. Linear regression of influences on soil nutrients availability. Positive and negative values are related with slope signs. P values are reported in parentheses, (*) are significant values ($p < 0.05$).

	Positive	**Negative**
Soil Physics → Soil Nutrients		
Sand	CN* (0.010), Ca* (0.013), pH H2O* (0.003), P (0.282), Fe (0.458), Mn (0.164), Mg (0.108), K (0.957), pH KCl (0.076)	Al* (0.025), Zn* (0.033), C (0.704), N (0.061), CEC (0.363)
Clay	Zn* (0.022), Al (0.063), N (0.119), CEC (0.649)	Ca* (0.033), pH H2O* (0.014), CN* (0.006), P (0.150), Fe (0.578), Mn (0.245), Mg (0.164), K (0.798), C (0.997), pH KCl (0.089)
Density	Fe* (0.001), pH KCl* (0.007), pH H2O (0.053)	Al* (0.000), Mn* (0.001), K* (0.000), C* (0.000), N* (0.000), Mg* (0.014), CEC* (0.002), P* (0.016), Zn (0.174), Ca (0.062), CN (0.577)
Litter Biomass → Soil Nutrients		
Leaf	Al (0.989), Fe (0.83), Ca (0.654), Mg (0.793), C (0.980), CEC (0.789), CN (0.692)	P* (0.052), Zn (0.570), Mn (0.976), K (0.575), N (0.808), pH H2O (0.679), pH KCl (0.742)
Branch	Al* (0.032), Fe (0.13), C (0.557), N (0.514), CN (0.632)	ZN* (0.026), P (0.626), Mn (0.229), Ca (0.525), Mg (0.604), K (0.392), pH H2O (0.088), pH KCl (0.086), CEC (0.721)
Charcoal	CN (0.529), Al (0.798)	P (0.723), Fe (0.925), Zn (0.692), Mn (0.399), Ca (0.370), Mg (0.991), K (0.800), C (0.632), N (0.643), pH H2O (0.617), pH KCl (0.293), CEC (0.547)
Residue	Fe* (0.038), Al (0.103), C (0.999), N (0.716)	pH KCl* (0.048), Zn (0.054), P (0.704), Mn (0.880), Ca (0.346), Mg (0.669), K (0.074), pH H2O (0.079), CEC (0.429), CN (0.081)
Litter Nutrients → Soil Nutrients		
Leaf	N (0.649), K (0.101), Ca (0.150), Mg	P (0.232), Zn (0.890)

	(0.204), Fe (0.408), Mn (0.723), C (0.980)	
Branch	Mg* (0.020), N* (0.034), K* (0.004), P (0.648), Ca (0.166), , Fe (0.708), Zn (0.315), Mn (0.091), C (0.557)	-
Charcoal	P (0.715), K (0.131), Ca (0.919), Mg (0.400), Fe (0.521)	N (0.302), Zn (0.575), Mn (0.773), C (0.632)
Residue	K* (0.000), Mg* (0.025), N (0.713), P (0.635), Ca (0.182), Fe (0.267), Zn (0.074), Mn (0.175), C (0.999)	-

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