UNIVERSIDADE ESTADUAL DO MARANHÃO
CENTRO DE CIÊNCIAS AGRÁRIAS
PROGRAMA DE PÓS-GRADUAÇÃO EM AGROECOLOGIA
CURSO DE MESTRADO EM AGROECOLOGIA

JESÚS ENRIQUE BURGOS GUERRERO

DIVERSIDADE E COMPOSIÇÃO DA MACROFAUNA DO SOLO NO SISTEMA AGROFLORESTAL QUESUNGUAL, NA AGRICULTURA DE CORTE QUEIMA E EM SUCESSÕES FLORESTAIS NA AMAZÔNIA ORIENTAL

São Luís - MA
2017

JESÚS ENRIQUE BURGOS GUERRERO
Engenheiro Agrônomo

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Orientador: Prof. Dr. Guillaume Xavier Rousseau

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Aprovada em: / /

BANCA EXAMINADORA:

____
Prof. Dr. Guillaume Xavier Rousseau - UEMA

____
Profa. Dra. Danielle Camargo Celentano Augusto - UEMA

____
Prof. Dr. Glécio Machado Siqueira - UFMA

DEDICO

Este trabalho é dedicado para: minha mãe, CLEMENTINA DE JESÚS GUERRERO DIAZ; meu pai, JORGE ENRIQUE BURGOS CABRERA e meu irmão ERNESTO CAMILO BURGOS GUERRERO. Infinita Gratidão pela vida, inspiração, companhia e incondicional apoio. Igualmente gratidão para meus primos e amigos, todos estão no meu coração.

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Eu sei de um país verde como uma maçã
Doce país de milho e laranjas
Sei de um país de palmeiras e montanhas
Doce país que tem sabor de coco e cana
Te levo, te sinto, te amo e te quero

E vou te cuidar com tua água e teu ar
E eu vou me educar, porque a terra não se canse
E eu vou te cuidar por tuas florestas e teus mares
E eu vou me educar para te querer sempre e sempre mais.

Sei de um país verde como uma maçã
Doce lugar de milho e laranjas
Doce lugar, eu quero vê-lo sempre bem
Sempre alegre, sempre verde, sorrir e florescer

Ricardo Williams

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O Sistema Agroflorestal Quesungual (QAS) originário da América Central, pode ser uma alternativa sustentável para os produtores familiares de pequena escala na Amazônia Oriental, onde a intensificação da agricultura com corte e queima ameaça o meio ambiente e sua subsistência. Este é o primeiro experimento para testar esse sistema na região amazônica. Para a avaliação do seu impacto na qualidade do solo nos determinamos a abundância e riqueza da macrofauna do solo e os atributos físicos e químicos do solo no QAS, agricultura de corte e queima (SB) e capoeiras (SF) de diferentes idades de pousio em comparação com florestas maduras (MF) no município de Alcântara, estado do Maranhão. Em total 32 áreas (40 X 50 m) foram avaliadas; as análises de dados incluíram modelos mistos, cluster e RDA. As comunidades da macrofauna foram sensíveis indicadores do sistema do uso do solo, especialmente predadores, organismos saprófagos e transformadores da serapilheira. Os resultados indicam que QAS e MF conservam similar densidade e riqueza da macrofauna, enquanto SB tem um forte impacto negativo sobre ela. O Sistema Agroflorestal Quesungual maximiza a acumulação de carbono orgânico no solo e representa uma alternativa viável para a promoção da conservação da biodiversidade e da seguridade alimentar na Amazônia Oriental.

Palavras chave: Macrofauna, floresta secundária, riqueza, densidade, Amazônia.

RESUMEN

El Sistema Agroforestal Quesungual (QAS) originario de América Central puede ser una alternativa sustentable para agricultores familiares de pequeña escala en la Amazonia Oriental, donde la intensificación de la agricultura con corte y quema amenaza el medio ambiente y su subsistencia. Este es el primer experimento para probar este sistema en la región Amazónica. Para evaluar su impacto en la calidad del suelo determinamos la abundancia y diversidad de la macrofauna, así como los atributos físicos y químicos del suelo en el QAS, agricultura con corte y quema (SB) y bosques secundarios (SF) de diferentes edades de barbecho en comparación con bosques maduros en el município de Alcântara, estado de Maranhão. En total 32 áreas (40 X 50 m) fueron evaluadas. El análisis de los datos incluyo modelos mixtos, clusters y RDA. La macrofauna fue un sensible indicador del sistema de uso de la tierra, especialmente predadores, organismos saprófagos y transformadores de la hojarasca. Los resultados indican que QAS y MF conservan similar riqueza y diversidade de la macrofauna, mientras que SB tiene un fuerte impacto negativo en ella. El Sistema Agroforestal Quesungual maximiza la acumulación de carbono orgánico en el suelo y representa una alternativa viable para promover la conservación de la biodiversidad del suelo y la seguridad alimentaria en la Amazonia Oriental.

Palabras clave: Macrofauna, bosque secundario, riqueza, densidad, Amazonia.

CAPÍTULO I

1 INTRODUÇÃO

Na atualidade são muitos os esforços para substituir o uso do sistema de agricultura de corte e queima (PEDROSO et al., 2008). Esse sistema é sustentável e até pode favorecer a biodiversidade (PEDROSO et al., 2008; PADOCH; PINEDO-VASQUEZ, 2010; LAWRENCE et al., 2010), mas para seu adequado funcionamento precisa de alta disponibilidade de terras e prolongados períodos de pousio. (BARRIOS et al., 2005; PEDROSO et al., 2008; PADOCH; PINEDO-VASQUEZ, 2010; LAWRENCE et al., 2010), condições cada vez mais difíceis de conseguir no atual contexto de forte pressão demográfica (METZGER, 2003; MERTZ et al., 2009; VAN VLIET et al., 2012).

Para sua substituição várias alternativas têm sido propostas (PEDROSO et al., 2008), muitas delas baseadas no uso de sistemas agroflorestais. Uma dessas alternativas é o chamado Sistema Agroflorestal Quesungual, desenvolvido e praticado em Honduras, América Central, por comunidades indígenas há séculos (HELLIN et al., 1999). O sistema foi criado para a gestão do solo em áreas de encosta, com solos facilmente degradáveis, períodos de seca prolongados e onde o fogo era tradicionalmente utilizado para a limpeza das áreas de cultivo.

Embora na Amazônia Oriental, não sejam encontrados declives acentuados ou encostas, todos os outros fatores que caracterizam o Sistema Agroflorestal Quesungual estão presentes na região de estudo, o que sugere que que esse sistema também pode ser viável para essa região da Amazônia.

Por outro lado a densidade e diversidade da macrofauna do solo é uma forma eficaz e rápida de avaliar o impacto de novas estratégias de manejo da terra (LOBRY DE BRUYN, 1999) já que estes organismos são fortemente afetados pelas mudanças nas condições do seu ambiente (DECAËNS, 2010; POSTMA BLAAUW et al., 2012; BARETTA et al., 2014).

Nesse contexto, esse trabalho teve como objetivo caracterizar a densidade e a diversidade da macrofauna edáfica no Sistema Agroflorestal Quesungual, em sistema tradicional de cultivo com fogo e nas florestas secundárias e maduras da

Amazônia oriental.

2 REVISÃO DE LITERATURA

2.1 Macrofauna do solo

A macrofauna do solo refere-se aos invertebrados do solo, cujo diâmetro corporal varia entre 2 mm e 20 mm (facilmente visíveis ao olho nú) e que vivem dentro ou sobre a superfície do solo em todas ou pelo menos uma das fases do seu ciclo de vida (KEVAN, 1968; SWIFT et al, 1979; BRAWN et al., 2009). Para seu melhor estudo, esses invertebrados edáficos são divididos em diferentes níveis de identificação taxonômica ou táxons (classes, ordens e famílias) (BRAWN et al., 2009).

Estes organismos são muito importantes já que desempenham um papel chave no funcionamento do solo e dos ecossistemas em geral, modificando seu ambiente através da participação ativa nos ciclos biogeoquímicos, contribuindo no desenvolvimento estrutural do solo (SILVA et al., 2006) e aumentando a porosidade, agregação e retenção da água, através da formação de estruturas como túneis ou câmaras (LAVELLE; SPAIN, 2001; AIRA et al., 2008). Por isso, em alguns casos são chamados os engenheiros do ecossistema (LAVELLE et al., 2006).

A presença das populações da macrofauna do solo nos agroecosistemas é um fator importante para a sustentabilidade dos sistemas agrícolas (BRUSSAARD et al., 2007), já que esses organismos além de serem atores nas funções do solo (MARICHAL et al, 2014) também podem servir como indicadores das mudanças no seu ambiente (VASCONCELLOS et al., 2013; MARICHAL et al., 2014).

2.2 Principais grupos taxonômicos da macrofauna do solo.

Alguns dos grupos taxonômicos da macrofauna do solo mais importantes por sua alta abundância e sensibilidade aos distúrbios ou mudanças no ambiente em que vivem são:

O ordem Isóptera (cupins) e a família Formicidae (formigas), são insetos sociais, amplamente distribuídos no mundo e com alta capacidade de adaptação a diferentes tipos de habitats. Mas também são sensíveis a prolongadas ou extremas alterações do ambiente, variando em sua abundância, dominância ou diversidade (BAUTISTA et al., 2009). São utilizados em estudos de biodiversidade, monitoramento, fragmentação e processos de restauração (BACCARO, 2006; COSTA et al., 2100; PAIS; VARANDA, 2010; ROUSSEAU et al., 2010).

A Classe Oligochaeta (minhocas) é fundamental no funcionamento do solo por sua estreita relação com a dinâmica da matéria orgânica (FRAGOSO et al., 1997) e por seu aporte direto na estrutura do solo com sua movimentação no perfil, e a formação de estruturas biogênicas altamente estáveis (BLANCHART et al., 2004). Sendo altamente influenciadas por práticas de manejo do solo (BARTZ et al., 2014) e favorecidas pela presença de matéria orgânica e cobertura morta (FONTE et al., 2009).

O ordem Coleóptera (besouros) é um dos mais diversos grupos no total de insetos descritos no mundo (ORGIAZZI et al., 2016). Eles contribuem diretamente nos processos de decomposição da matéria orgânica, ciclagem de nutrientes e movimentação do solo, sendo capazes de explorar uma alta diversidade de nichos ecológicos (ORGIAZZI et al., 2016).

Por sua vez, predadores como Araneae (aranhas), Opilionida, Chilopoda (piolhos de cobra) e Pseudoscorpionida são especialmente relacionados com ecossistemas estaveis e a presença desses grupos é sinal de um fluxo normal de energia dentro da cadeia trófica do ecosistema. (ROUSSEAU et al., 2014)

Outros invertebrados como Isopodos (tatuzinhos), Diplopodos (centopéias), Gastropodos (lesmas e caracóis) também são amplamente sugeridos como indicadores do funcionamento do solo, por sua estreita relação com ambientais mais complexos e estáveis, com maior conteúdo de carbono orgânico e pela sensibilidade aos distúrbios naturais ou antropogênicos (VASCONCELLOS et al., 2013; MORON-RIOS et al., 2010; BARETTA et al., 2011; TIZADO; NUÑES-PEREZ, 2016).

2.3 Agricultura de corte e queima

Há milênios na região amazônica, a conversão das áreas florestais primárias ou secundárias em áreas de cultivos agrícolas se faz através da chamada agricultura com corte e queima (PEDROSO et al., 2008; BARNI et al., 2012). Esse é um sistema sustentável quando é praticado da forma correta, em grandes áreas florestais, com baixas densidades populacionais, adequados sistemas de plantação e longos períodos de pousio (KLEINMAN et al., 1995; JOHNSON et al., 2001; MENDOZA-VEGA et al., 2003; PEDROSO et al., 2008). Sendo capaz de manter ou inclusive promover a biodiversidade (PEDROSO et al., 2008).

Seus componentes básicos são o corte da vegetação primária ou secundária, a queima do material vegetal cortado, o cultivo e o pousio ou período de regeneração da vegetação cortada (KLEINMAN et al., 1995; PEDROSO et al., 2008). O período de cultivo geralmente tem uma duração de um até dois anos, logo, o período de pousio tem que ser muito mais longo que o período de cultivo (KLEINMAN et al., 1995; PEDROSO et al., 2008; MERTZ et al., 2009).

Entre as vantagens dessa prática está a facilitação dos tratos culturais após a queimada, a eliminação de ervas espontâneas, pragas, doenças e principalmente a adição de nutrientes constituintes da cinza que melhoram as propriedades químicas do solo (KLEINMAN et al., 1995; PEDROSO et al., 2008; MERTZ et al., 2009).

No entanto, no atual contexto de alta pressão demográfica e alta demanda de terras (MERTZ et al., 2009; VAN VLIET et al., 2012), os adequados períodos de pousio são cada vez menos praticados (COOMES et al., 2000; METZGER 2003; LAWRENCE et al., 2010), com importantes consequências na sustentabilidade do sistema. Além disso a agricultura com corte e queima é questionada por sua participação no processo de desmatamento, perda de biodiversidade (PEDROSO et al., 2008), aquecimento global devido as emissões de CO_2 e degradação dos solos. (COE et al., 2013),

2.3.1 Efeito do fogo no solo

No que se refere ao solo, o uso do fogo tem importantes consequências nas propriedades físicas, químicas e biológicas (MOURA et al., 2009; LAWRENCE et al., 2010; ROSSI et al, 2010). Principalmente pela alta temperatura que pode alcançar o solo (400 °C) (MATLACK, 1993; GIMENO-GARCÍA et al., 2004), evaporação da agua e a eliminação da matéria orgânica (VERMA; JAYAKUMAR, 2012).

O pH pode aumentar pela adição das cinzas, caraterizadas por ter alto pH (MOLINA et al., 2007). A densidade aparente aumenta devido ao colapso dos agregados, afetando negativamente a porosidade e permeabilidade do solo (CERTINI, 2005). Os componentes da textura do solo (areia, silte e argila) têm limiares de alta temperatura e geralmente não são afetados pelo fogo (VERMA; JAYAKUMAR, 2012),

O conteúdo de nutrientes do solo pode variar segundo o tipo de elemento, mas geralmente resulta em um incremento na sua disponibilidade (KUTIEL; NAVEH, 1987). O carbono orgânico diminui, o cálcio aumenta e os estoques de magnésio, potássio e fósforo permanecem sem maiores variações (GARCÍA-OLIVA et al., 1999; NEFF et al., 2005; MERTZ et al., 2009).

Por sus vez, a biota do solo diminui consideravelmente. Principalmente as populações de organismos como fungos e bactérias (DAHLBERG et al., 2001) e comunidades de invertebrados (BARROS et al., 2002; BARRIOS et al., 2005; SAINT-GERMAIN et al., 2005; BUDDLE et al., 2006), os quais sucumbem diretamente pelas chamas e gases quentes ou indiretamente pela destruição de suas fontes de comida e abrigo (MATHIEU et al., 2005; ROSSI et al., 2010).

2.4 Alternativas ao sistema de agricultura de corte e queima.

Na atualidade muitos governos e organizações no mundo inteiro fazem esforços para a substituição da agricultura de corte e queima por práticas menos agressivas ao meio ambiente (PEDROSO et al., 2008; COE et al., 2013). Várias alternativas tem sido sugeridas, entre elas o uso de coberturas mortas

(NORGROVE; HAUSER, 2002; VIELHAUER et al., 2004; DENICH et al., 2005), o cultivo em aléias (MOURA et al 2014), o plantio direto (BARTZ et al., 2014) e a implementação de Sistemas Agroflorestais ou SAFs (DASH; MISRA, 2001; FAGERSTRÖM et al., 2002, VIELHAUER et al., 2004; PINHO et al., 2012).

Os SAFs tem especial destaque por serem um sistema de produção que favorece a diversidade de plantas, a conservação do solo, a provisão de serviços ambientais e que dá considerável renda para os agricultores (WELCHES et al., 2008; ROUSSEAU et al., 2013; CARDOZO et al., 2015).

O Centro Mundial Agroflorestal (ICRAF), define os SAFs como sistemas e tecnologias de uso da terra que combinam árvores florestais com culturas agrícolas, pastagens e ou animais, dependendo do tempo e espaço para aumentar e otimizar a produção de forma constante (NAIR, 1993).

2.5 Sistema Agroflorestal Quesungual

Entre as alternativas foi proposto um sistema praticado por comunidades indígenas de Honduras, América Central, há centenas de anos (HELLIN et al., 1999). Esta antiga prática agroflorestal foi observada e descrita por pesquisadores da FAO na década de 1990 e chamada sistema agroflorestal Quesungual pela comunidade onde foi identificado pela primeira vez (HELLIN et al., 1999; PAULI et al., 2011).

Este é um sistema de produção para pequenos agricultores, que inclui um pacote de tecnologias para o manejo sustentável da vegetação, do solo e da água em áreas de encosta com tendência de seca no trópico sub-úmido (CIAT, 2009).

Esse sistema sustenta-se em quatro princípios básicos (CIAT, 2010)

- Não corte e queima, mediante a gestão corte e poda (parcial, seletiva e progressiva) da vegetação nativa.
- Cobertura permanente do solo, por meio da deposição contínua de biomassa

de árvores, arbustos, ervas espontâneas e ou resíduos de culturas.

- Mínima perturbação do solo através do plantio direto.
- Uso eficiente de fertilizantes, através da sua aplicação adequada no tempo, tipo, quantidade e localização.

Para sua implementação, as árvores e arbustos com algum tipo de interesse madeireiro ou frutíferos são deixados em pé, enquanto que, o material vegetal restante é cortado a uma altura de 1,5 metros, sem machucar o tronco nem a raiz, para permitir sua regeneração posterior. Todo o material podado é cortado e usado como cobertura morta sobre a área total de cultivo (FAO, 2005).

2.5.1 Vantagens da implementação do Sistema Agroflorestal Quesungual

Existem diversas vantagens na implementação deste sistema (CIAT, 2010).

- Incremento paulatino da produtividade, garantindo a segurança alimentar dos camponeses.
- Constante fornecimento de lenha para uso doméstico.
- Melhoria na prestação de serviços ecossistêmicos por incremento no sequestro de carbono e diminuição da erosão do solo, redução do desmatamento e da emissão de gases efeito estufa;
- E a conservação da biodiversidade local e a proteção do recurso água, solo e vegetação.

Além disso, vários estudos afirmam que esse sistema permite aproveitar a área de cultivo por mais tempo (> 7 anos) enquanto que nos sistemas de agricultura com corte e queima após 2 ou 3 anos as áreas são abandonadas (PAULI et al., 2011).

3. OBJETIVO

Determinar e comparar a densidade e diversidade da macrofauna do solo no Sistema Agroflorestal Quesungual, na agricultura com corte-queima, em florestas secundarias e em florestas maduras da Amazonia oriental.

4. HIPÓTESE

O Sistema Agroflorestal Quesungual pode manter a mesma densidade e diversidade da macrofauna do solo que as áreas florestais melhor conservadas.

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CAPÍTULO II

Artigo escrito de acordo com as normas da revista Agriculture, ecosystems and environment

Quesungual Agroforestry System conserves soil macrofauna density and richness of the Amazon forest

Jesús Burgos-Guerrero[1], Luis Hernández-García[1], Ernesto Gomez[1], Stefania Triana[1], Julio Cesar Bravo[1], Danielle Celentano[1], Guillaume Xavier Rousseau[1,2] *

[1] Agroecology Graduate Program (PPGAgroecologia), State University of Maranhão (UEMA), Campus Universitário Paulo VI, s/n, Tirirical, 65054-970, São Luís, MA, Brazil.

[2] Biodiversity Research Program (PPBIO) Amazônia Oriental, Ministry of Science, Technology, Innovation and Communication (MCTI), Brazil.

* correspondent author: guilirou@yahoo.ca

Abstract: The Quesungual agroforestry system (QAS) from Central America may be a suitable alternative for small-scale family farming in eastern Amazon, where the intensification of slash-and-burn agriculture threats environment and livelihood. This is the first experiment to test this system in the Amazon region. To evaluate its impact on soil quality we assessed soil macrofauna abundance and diversity, soil physical and chemical attributes in QAS, slash-and-burn agriculture (SB) and secondary forests (SF) from different ages of fallow in comparison with mature forests (MF) in Alcantara County, Maranhao state. In total, 32 plots (40 X 50 m) were evaluated; data analysis included mixed models, clustering and RDA. Macrofauna community was a very sensitive indicator of land use systems, especially predators, saprophagous organisms and litter transformers. Results indicate that QAS and MF conserve similar density and richness of macrofauna, while SB had a strong negative impact on it. The Quesungual agroforestry system maximizes soil organic carbon accumulation and represents a viable alternative to promote both soil biodiversity conservation and food security in eastern Amazon.

Key worlds: Macrofauna, secondary forest, richness, density, Amazon

Introduction

Slash-and-burn agriculture or shifting cultivation has been practiced for thousands years in the tropics (Pedroso et al., 2008; Barni et al., 2012). It is considered a sustainable agricultural method in conditions of low population density, high land availability and long fallow periods (Pedroso et al., 2008; Padoch and Pinedo-Vasquez, 2010; Lawrence et al., 2010). However, the increase of population and its demand for agricultural lands are leading agriculture into a process of intensification (Metzger, 2003; Mertz et al., 2009; van Vliet et al., 2012), causing the reduction of fallow periods and making those systems increasingly less productive and sustainable (Ayarza et al., 2010). Indeed slash-and-burn agriculture is often associated with deforestation, global warming, soil degradation and biodiversity loss (Pedroso et al., 2008; Coe et al, 2013). For these reasons, academic institutions, governments and non-governmental organizations are seeking for alternatives to replace its use (IFA, 2001; Coe et al., 2013).

Proposed alternative practices have included alley cropping (Moura et al., 2009), mulching (Vielhauer et al., 2004) no-tillage (Baretta et al., 2014) and agroforestry systems (Pinho et al., 2012). The Quesungual agroforestry system is based on the sustainable management of vegetation, water and soil resources (CIAT, 2009). The system consists in cutting and pruning the natural vegetation to provide permanent soil cover and permit trees and shrubs to regenerate within the crop field. The natural regeneration protects the soil from erosion, produces biomass for additional pruning and allows a fast recovery of forest coverage when the land is abandoned (CIAT, 2009; Pauli et al., 2011). On average, crop rotations last 7 years, after which the land is abandoned (Pauli et al., 2011). The name Quesungual comes from the Honduran indigenous community, in Central America, where it was first identified (Hellin et al., 1999). Although the system was originally created for hillside areas, it seems to be adaptable to the eastern Amazon region, which also has long periods of drought, low fertility soils, susceptibility to erosion and common use of the slash-and-burn agriculture. However, both the productivity and sustainability of this method must be evaluated in the Amazon region.

Soil macrofauna community is considered as a good indicator of soil quality and agricultural sustainability (Brussaard et al. 2007). These invertebrates play a key role in the provision of soil ecosystem services as their density and diversity are associated with best soil functioning (Lavelle et al., 2006; Rousseau et al., 2014). Indeed, large taxonomic groups of soil macrofauna (class, order or family) are often used to evaluate soil management strategies and the restoration process (Lobry de Bruyn, 1999; Vasconcellos et al., 2013; Rousseau et al., 2013), given that they are strongly influenced by land use systems and produce fast and reliable results (Lavelle et al., 2006; Marichal et al., 2014; Moura et al., 2014). In Central America, Rousseau et al. (2012) found that the abundance of macrofauna groups was a good indicator of soil quality in Agroforestry systems compared to mature forests.

As far as we know it is the first experiment to test the Quesungual agroforestry system in the Amazon region of Brazil. This study aimed to characterize and compare the density and diversity of the soil macrofauna groups in the Quesungual agroforestry system, slash-and-burn agriculture, secondary forest and mature forest in Maranhão, eastern Amazon. Our hypothesis is that the Quesungual agroforestry system can host the same density and diversity of soil invertebrates as that of the conserved forest remnants.

Materials and methods

Study area

The study was conducted in five villages in the county of Alcântara, northern Maranhão state, Brazil (02º19'17'' - 02º24'05'' S and 44º25'42''- 44º28'49'' W) (Figure 1). This region is part of the Eastern Amazon biome (IBGE, 2002); the climate is tropical, according to the classification system of Köppen (Alvares et al., 2013), with two well-defined seasons: a rainy season from January to June and a dry season from July to December. The average annual precipitation varies between 1,000 and 1,800 mm, with an average temperature of 25 °C (Brito and Rego, 2001). The soil is classified as Plinthosol (Anjos et al., 1995) characterized by low fertility and poor cohesion (Moura et al., 2014). The landscape is dominated by young secondary forests, some old forest fragments (Zelarayán et al., 2015) and areas with slash-and-burn agriculture. The population is very poor and relies on the slash-and-burn agriculture for subsistence (Celentano et al., 2014).

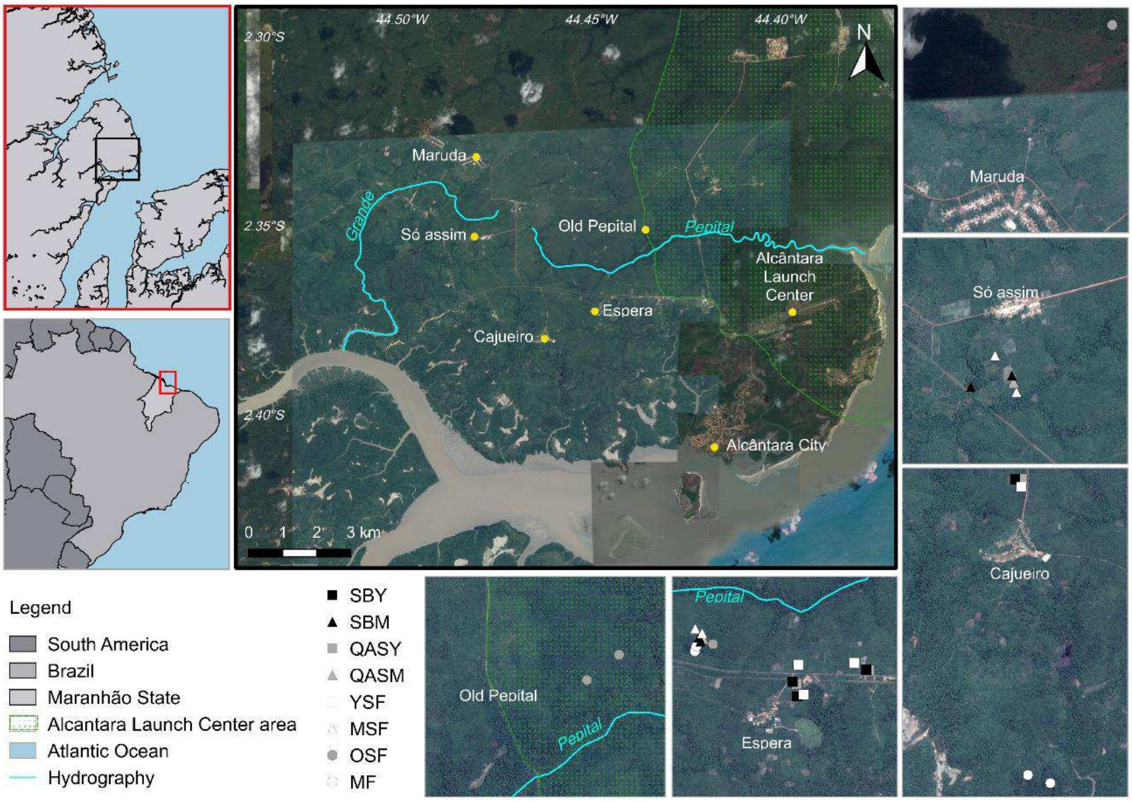

Figure 1. Location of study areas in Alcântara County, Maranhão state, Brazil. Land uses: SBY= slash-and-burn agriculture from early-succession secondary forests, SBM= slash-and-burn agriculture from intermediate-succession secondary forests, QASY= Quesungual agroforestry system from early-succession secondary forests, QASM= Quesungual agroforestry system from intermediate-succession secondary forest, YSF= early-succession secondary forests, MSF= intermediate-succession secondary forests, OSF= advanced-succession secondary forests, MF= Mature forest.

2.2. Experimental design

The experimental design was comprised of eight land uses, each one with four replicates: MF - mature forest (> 120 yr-old, with selective logging); YSF - early-succession secondary forests (3 to 6 yr-old); MSF - intermediate-succession secondary forests (7 to 12 yr-old); OSF - advanced-succession secondary forests (30 to 40 yr-old); SBY - slash-and-burn agriculture from early-succession secondary forests*;* SBM - slash-and-burn agriculture from intermediate-succession secondary forests; QASY - Quesungual agroforestry system from early-succession secondary forests; QASM - Quesungual agroforestry system from intermediate-succession secondary forests. Forest ages (time since last slash-and-burn) were reported by each landowner (Table 1).

Table 1. Description of plots and land uses in Alcântara County, Maranhão state, Brazil.

Land use	Abbreviation	Sampling year	Village	Coordinates		Succession age (years)
				South	West	
Slash-and-burn agriculture from early-succession secondary forests	SBY	2015	Cajueiro	S 02°22'24"	W 44°27'45"	4
	SBY	2015	Espera	S 02°22'13"	W 44°26'42"	3
	SBY	2016	Espera	S 02°22'08"	W 44°26'44"	4
	SBY	2016	Espera	S 02°22'04"	W 44°26'19"	5
Slash-and-burn agriculture from intermediate-succession secondary forests	SBM	2015	Só assim	S 02°21'26"	W 44°28'40"	8
	SBM	2015	Espera	S 02°21'55"	W 44°27'14"	7
	SBM	2016	Só assim	S 02°21'28"	W 44°28'49"	7
	SBM	2016	Espera	S 02°21'53"	W 44°27'15"	7
Quesungual agroforestry system from early-succession secondary forests	QASY	2015	Cajueiro	S 02°22'24"	W 44°27'42"	4
	QASY	2015	Espera	S 02°22'09"	W 44°26'42"	3
	QASY	2016	Espera	S 02°22'09"	W 44°26'42"	3
	QASY	2016	Espera	S 02°22'04"	W 44°26'18"	3
Quesungual agroforestry system from intermediate-succession secondary forests	QASM	2015	Só Assim	S 02°21'27"	W 44°28'40"	8
	QASM	2015	Espera	S 02°21'54"	W 44°27'14"	7
	QASM	2016	Espera	S 02°21'54"	W 44°27'13"	7
	QASM	2016	Só Assim	S 02°21'27"	W 44°28'40"	7
Early-succession secondary forests	YSF	2015	Espera	S 02°22'13"	W 44°26'40"	5
	YSF	2015	Cajueiro	S 02°22'26"	W 44°27'43"	4
	YSF	2016	Espera	S 02°22'02"	W 44°26'23"	4
	YSF	2016	Espera	S 02°22'03"	W 44°26'42"	5
Intermediate-succession secondary forests	MSF	2015	Espera	S 02°21'52"	W 44°27'14"	7
	MSF	2015	Só Assim	S 02°21'29"	W 44°28'39"	8
	MSF	2016	Só Assim	S 02°21'21"	W 44°28'44"	10
	MSF	2016	Espera	S 02°21'51"	W 44°27'16"	10
Advanced-succession secondary forests	OSF	2015	Espera	S 02°21'56"	W 44°27'10"	>30
	OSF	2015	Maruda	S 02°19'17"	W 44°28'28"	>30
	OSF	2016	Pepital	S 02°21'02"	W 44°25'48"	>30
	OSF	2016	Pepital	S 02°20'57"	W 44°25'42"	>30
Mature forest.	MF	2015	Espera	S 02°21'58"	W 44°27'16"	>120
	MF	2015	Cajueiro	S 02°24'02"	W 44°27'40"	>120
	MF	2016	Espera	S 02°21'57"	W 44°27'16"	>120
	MF	2016	Cajueiro	S 02°24'05"	W 44°27'33"	>120

The Quesungual agroforestry and slash-and-burn systems were implemented in 40 x 50 m plots (0.2 ha) in October 2014 and 2015. To prepare the slash-and-burn plots, all vegetation inside the plots were cut, evenly distributed and burned (after two months when it was completely dry). Cassava (*Manihot esculenta Crantz*) and maize (*Zea mays*) were planted at the beginning of the rainy season (March 2015 and February 2016). To prepare the Quesungual plots, trees were pruned to 1.5m of height and those of interest (fruit and timber) were left standing, then the material (leaves and branches) were placed as mulching throughout the plot (FAO, 2005). In March 2015 and February 2016, we planted cassava, maize, pigeon peas (*Cajanus cajan*) and jack beans (*Canavalia ensiformis*) as green manure (Figure 2). Before the sowing the plots were manured with limestone (2 Mg/ha) and rock phosphate (0.24 Mg/ha).

Figure 2. The eight land-use evaluated in Alcântara County, Maranhão state, Brazil. Land uses: SBY = slash-and-burn agriculture from early-succession secondary forests, SBM= slash-and-burn agriculture from intermediate-succession secondary forests, QASY= Quesungual agroforestry system from early-succession secondary forests, QASM= Quesungual agroforestry system from intermediate-succession secondary forests, YSF= early-succession secondary forests, MSF= intermediate-succession secondary forests, OSF= advanced-succession secondary forests, MF= Mature forest.

Soil macrofauna sampling

Sampling was carried out in May 2015 and June 2016 (end of the rainy season). Macrofauna were collected according to the modified Tropical Soil Biology and Fertility method (TSBF, Anderson and Ingram, 1993). Five soil monoliths of 0.25 x 0.25 m and 0.10 m depth, were extracted in a cruciform shape from each plot, with one central monolith and one 20 m apart in each direction (North, South, East and West). The macrofauna (soil invertebrates with 2 mm<body diameter<20 mm) were hand-sorted from litter and soil separately, preserved in 99% alcohol and identified as to large taxonomic (class, order or family) and functional groups (according to the dietary or behavioral habits) (Brawn, 2001; Swift et al., 2010). The specimens captured were deposited in the Soil Invertebrates Collection of the Maranhão State University (UEMA).

Soil analysis

Five soil samples were sampled in each plot (one next to each monolith) from 0 to 10 cm depth, with volumetric rings of 282.6 cm^3 volume. The soil was weighed wet and divided into sub-samples according to the type of analysis. For determination of moisture content and bulk density, a 40 g soil sub-sample was oven-dried at constant temperature (105 °C for 48 hours) and the moisture percentage was calculated with $((ww\text{-}dw) / dw) \times 100$ and the bulk density with dw/v where ww is the wet weight of the sample, dw its dry weight and v the ring volume. For the soil particle-size and chemical analysis, the soil was air-dried and passed through a 2 mm sieve. Textural composition was determined according to the pipette method (Embrapa, 1997). For chemical analysis, we followed the procedures of the Agronomic Institute of Campinas (van Raij et al., 2001) in order to determine the pH (0.01 M suspension in CaCl2), total organic carbon content (by combustion), P, exchangeable K, Ca, Mg, Na (Resin) and H+Al (SMP method). We also calculated the cation exchange capacity as K+Ca+Mg+(H+Al) and sum of bases as K+Ca+Mg.

Statistical analysis

We calculated the total density of soil macrofauna as the sum of all individuals across taxa per square meter (ind/m^2) and assessed diversity through plot richness and mean taxa richness (number of taxa per sample) and the Shannon-Weaver and Pielou indices (adapted from Bandeira et al., 2013). To determine the effect of the land use system on the macrofauna characteristics (density and diversity) and soil properties, we performed generalized linear mixed models (GLMM) by maximum likelihood with negative binomial distribution for all taxa except Auchenorryncha and Dermaptera, for which the Poisson distribution was used. In the GLMM, land uses served as the fixed factor whereas the sampling year and sampling location were the random factors. For the choice of most parsimonious models, we used the lowest values of the Akaike information criterion (Di Rienzo et al., 2011). Mean comparison was performed according to the Tukey test, with significance level of $p \leq 0.05$.

The degree of similarity between the land uses was determined by the Bray-Curtis index with graphic representation as dendrogram. This index of association expresses the similarity between groups, sites or environments based on abundance of species or taxa (Legendre and Legendre, 1998).

The relationship between the soil macrofauna and the soil physical and chemical attributes was studied through Canonical Redundancy Analysis (RDA). This method represents the relationship between biotic and abiotic variables, where X is the matrix of explanatory variables (soil attributes) and Y is the matrix of response variables (soil macrofauna) (Legendre and Legendre, 1998). We used the Forward Selection to select the soil attributes that best explain the macrofauna composition and test their significance. The soil macrofauna density and physico-chemical data were transformed by $Ln(x + 1)$ before performing RDA.

The analyses of diversity and association index were made with the statistical programs InfoStat student version 2016 (Di Rienzo et al., 2011). The mixed models and RDA analyses were performed with the software R (R Development Core Team 2009) using the packages lme4 (GLMM) (Bates et al., 2012) and vegan (RDA and collector curve; Oksanen et al., 2008).

Results

A total of 6,121 individuals were counted and classified into 24 taxonomic groups, of which the most abundant were Isoptera (33.1%), Formicidae (28.8%), Oligochaeta (16.9%), Coleoptera (4.6%), Chilopoda (3.7%), Araneae (3.6%), Diplura (1.4%), Gastropoda (1.2%), and Pseudoscorpionida (1.1%). The other groups represented less than 1% of total abundance (Table A1).

Mature Forest (MF) was the only land use with the presence of all 24 taxa found in the study. According to the collector curve, most of land uses were close to saturation, except in slash-and-burn agriculture from early-succession secondary forests (SBY) that showed an ascending pattern even at the 20th sample (Figure A1).

Soil macrofauna density and diversity

The total density and richness were highest in MF and Quesungual agroforestry system from intermediate-succession secondary forests (QASM), differing significantly from SBY (Table 2). On average, the MF had among 15 to 19 taxa per plot, QASM 14 to 18 and SBY 4 to 9. Other land uses had between 9 and 16 taxa per plot and were ranked as follows: MF > QASM > OSF > MSF > QASY > YSF > SBM > SBY. Although the Shannon-Weaver and Pielou equitability index also followed this trend, they did not differ statistically ($p \leq 0.81$ and $p \leq 0.96$). According to the mixed models, neither the year nor the location influenced the total density or taxa richness.

Comparing the agricultural areas, we found that age of the secondary forest slashed for the implementation of agricultural systems with or without employing fire showed significant influence on the density ($F = 19.5$; $p \leq 0.0001$) and richness ($F = 20.4$; $p \leq 0.0167$) of soil macrofauna.

Table 2. Soil macrofauna community-structure indices (mean and standard errors) in different land uses within Alcântara County, Maranhão state, Brazil.

Community Structure	Land Uses*								F	p
	SBY	SBM	QASY	QASM	YSF	MSF	OSF	MF		
Total Density	**246.4 ±91.6 b**	**436.0 ±91.2 ab**	**454.4 ±31.0 ab**	**920.8 ±149.3 a**	**486.4 ±259.4 ab**	**529.6 ±150.3 ab**	**824.8 ±494.3 a**	**1021.6 ±59.43 a**	**19.5**	**≤0.0068**
Mean Richness	**3.05 ±0.5 b**	**4.9 ±0.1 ab**	**6.3 ±0.1 ab**	**8.2 ±1.2 a**	**5.0 ±1.5 ab**	**7.1 ±0.3 ab**	**6.5 ±0.4 ab**	**9.8 ±1.1 a**	**20.4**	**≤0.0043**
Shannon index	0.62 ±0.1	1.12 ±0.02	1.36 ±0.03	1.31 ±0.2	1.1 ±0.04	1.47 ±0.07	1.34 ±0.1	1.64 ±0.1	-	≤0.8146
Pielou index	0.52 ±0.08	0.75 ±0.01	0.74 ±0.01	0.67 ±0.02	0.72 ±0.05	0.77 ±0.03	0.75 ±0.09	0.74 ±0.01	-	≤0.9695

Means with different letter indicate significant differences according to the Tukey test ($p \leq 0.05$). Land uses: SBY= slash-and-burn agriculture from early-succession secondary forests, SBM= slash-and-burn agriculture from intermediate-succession secondary forests, QASY= Quesungual agroforestry system from early-succession secondary forests, QASM= Quesungual agroforestry system from intermediate-succession secondary forests, YSF= early-succession secondary forests, MSF= intermediate-succession secondary forests, OSF= advanced-succession secondary forests, M*F*= Mature forest.

Soil macrofauna composition

Twelve taxa were found in all land use systems (Isoptera, Fomicidae, Oligochaeta, Coleoptera, Chilopoda, Araneae, Gastropoda, Pseudoscorpionida, Heteroptera, Diptera, Orthoptera and Lepidoptera), whereas two taxa (Auchenorryncha and Scorpionida) were exclusive in MF.

Eight taxa had densities that differed significantly between the land uses (Table A1). Formicidae density was higher in QASM without significant difference versus the majority of land uses except SBY. Oligochaeta was considerably more abundant in MF, the fallows and the Quesungual, while areas with slash-and-burn had the lowest abundances. Predators such as Araneae, Chilopoda and Pseudoscorpionida had the highest density in the MF and QASM. Diplopoda showed maximum density in MF followed by SBM; Gastropoda was more abundant in QASM than in others land uses. Ixodida had a high density in OSF and was not present in SBY or QASY.

The dendrogram based on Bray-Curtis index separated land uses in three groups (distance=1.05): (1) SBY; (2) MF and QASM; and (3) other land uses. The cluster analyses confirmed that QASM was very similar to the most conserved forests and that the SBY has a severely depleted macrofauna community. All other land uses maintained an intermediate status (Figure 3).

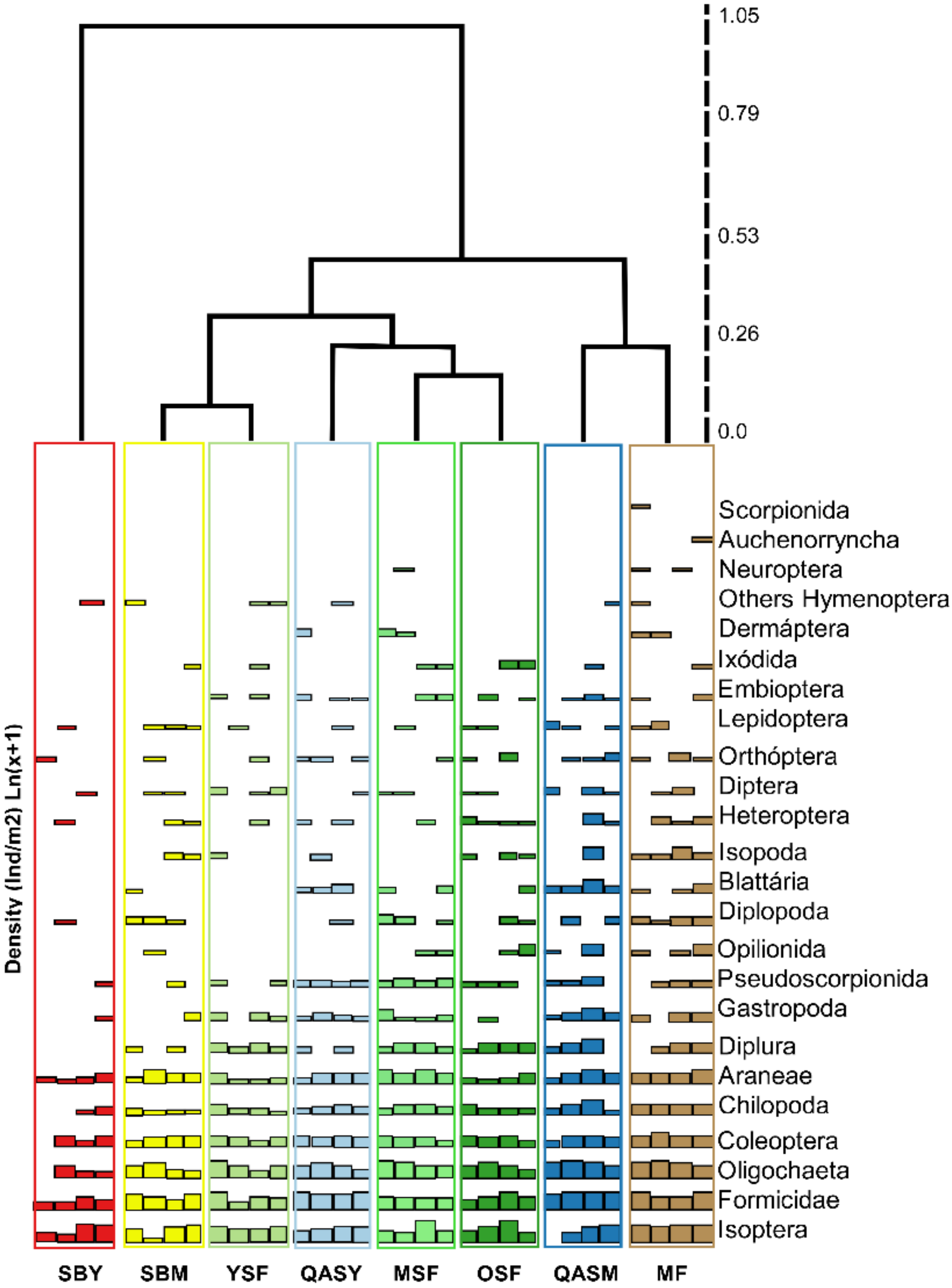

Figure 3. Density of soil macrofauna (ind/m^2) by taxa and dendogram of Bray-Curtis index in Alcântara County, Maranhão state, Brazil. Land uses: SBY= slash-and-burn agriculture from early-succession secondary forests, SBM= slash-and-burn agriculture from intermediate succession secondary forests, QASY= Quesungual agroforestry system from early-succession secondary forests, QASM= Quesungual agroforestry system from intermediate-succession secondary forests, YSF= early-succession secondary forests, MSF= intermediate-succession secondary forests, OSF= advanced-succession secondary forests, M*F*= Mature forest.

Soil attributes and macrofauna

Physical attributes of soil did not statistically differ among land uses. According to the chemical soil attributes, QASM presented the best agronomic quality. Organic Carbon contain ($F = 18.1$; $p \leq 0.0111$), Phosphorous ($F = 18.1$; $p \leq 0.0112$), Magnesium ($F = 22.5$; $p \leq 0.0020$), Cation Exchange Capacity ($F = 26.2$; $p \leq 0.0004$), Potential Acidity ($F = 58.8$; $p \leq 0.0443$) and Sum of Bases ($F = 14.4$; $p \leq 0.0001$) were significantly different between the land uses (Table 3).

Table 3. Physical and chemical attributes of soils (average and standard errors) in different land use in Alcântara County, Maranhão state, Brazil.

Soil attribute	United	SBY*	SBM*	QASY*	QASM*	YSF*	MSF*	OSF*	MF*	F	*P* value
Chemical attributes											
Organic Carbon	**Mg/ha**	**12.70 ±0.001 b**	**15.93 ±0.002 ab**	**12.76 ±0.001 b**	**19.45 ±0.003 a**	**17.38 ±0.002 ab**	**18.87 ±0.003 ab**	**16.37 ±0.002 ab**	**17.27 ±0.001 ab**	**18.1**	**≤0.0111**
pH	$CaCl_2$	4.7 ±0.21	4.7 ±0.27	5.1 ±0.2	5.2 ±0.2	4.4 ±0.18	4.2 ±0.2	4.1 ±0.2	4.1 ±0.2	-	0.9913
Phosphorous	**Mg/ha**	**0.02 ±0.004 b**	**0.04 ±0.010 ab**	**0.04 ±0.025 ab**	**0.08 ±0.046 a**	**0.02 ±0.003 b**	**0.03 ±0.006 ab**	**0.02 ±0.001 ab**	**0.03 ±0.006 ab**	**18.1**	**≤0.0112**
Potassium	Mg/ha	0.06 ±0.004	0.08 ±0.011	0.06 ±0.011	0.07 ±0.010	0.07 ±0.018	0.07 ±0.013	0.06 ±0.008	0.05 ±0.003	-	0.1962
Calcium	Mg/ha	0.28 ±0.062	0.41 ±0.094	0.37 ±0.062	0.52 ±0.126	0.31 ±0.073	0.34 ±0.136	0.17 ±0.066	0.31 ±0.125	-	0.1903
Magnesium	**Mg/ha**	**0.09 ±0.022 b**	**0.17 ±0.043 ab**	**0.13 ±0.035 ab**	**0.21 ±0.054 a**	**0.08 ±0.012 b**	**0.13 ±0.032 ab**	**0.09 ±0.016 ab**	**0.09 ±0.021 ab**	**22.5**	**≤0.0020**
Sodium	Mg/ha	0.05 ±0.0002	0.09 ±0.0006	0.07 ±0.0006	0.08 ±0.0007	0.07 ±0.0009	0.08 ±0.0006	0.08 ±0.0005	0.04 ±0.0002	-	0.5837
Cation Exchange Capacity	**$mmol_c/dm^{-3}$**	**50.59 ±4.1 c**	**77.83 ±12.3 c**	**58.6 ±2.3 bc**	**79.8 ±12.6 ab**	**78.6 ±6.1 ab**	**90.3 ±10.1 a**	**82.3 ±9.3 ab**	**83.1 ±4.1 ab**	**26.2**	**≤0.0004**
Potential Acidity	**$mmol_c/dm^{-3}$**	**28.05 ±3.0 b**	**41.45 ±11.4 ab**	**27.9 ±3.9 b**	**35.1 ±7.2 b**	**54.4 ±10.0 a**	**61.1 ±4.6 a**	**64.5 ±9,6 ab**	**58.6 ±8.6 a**	**58.8**	**≤0.0001**
Sum of Bases	**$mmol_c/dm^{-3}$**	**22.5 ±4.8 ab**	**36.3 ±8.2 ab**	**30.6 ±6.2 ab**	**44.6 ±10.3 a**	**24.2 ±4.3 ab**	**29.1 ±9.3 ab**	**17.7 ±4.6 b**	**24.5 ±7.9 ab**	**14.4**	**≤0.0443**
Physical attributes											
Soil moisture	%	8.0 ±1.2	12.3 ±2.3	11.2 ±0.8	11.9 ±2.5	11.7 ±2.2	11.9 ±1.9	10.8 ±1.5	9.6 ±2.2	-	0.4283
Bulk Density	g/cm^3	1.40 ±0.05	1.3 ±0.04	1.4 ±0.07	1.3 ±0.1	1.3 ±0.02	1.2 ±0.03	1.2 ±0.09	1.2 ±0.05	-	1.0000
Sand	%	75.7 ±3.4	80.6 ±2.1	80.2 ±0.7	77.2 ±0.7	76.6 ±1.5	77.4 ±1.6	80.7 ±1.6	79.3 ±1.1	-	0.9635
Silt	%	6.1 ±0.4	5.1 ±0.5	7.3 ±1.6	5.5 ±0.3	5.6 ±0.5	5.5 ±0.3	5.4 ±0.4	5.1 ±0.6	-	0.9164
Clay	%	18.2 ±3.0	14.3 ±1.7	14.7 ±0.9	17.3 ±0.4	17.3 ±1.3	17.1 ±1.4	14.5 ±1.5	15.6 ±0.7	-	0.7618

Means with different letter indicate significantly differences according with Tukey test ($p \leq 0.05$).
* SBY= slash-and-burn agriculture from early-succession secondary forests, SBM= slash-and-burn agriculture from intermediate-succession secondary forests, QASY= Quesungual agroforestry system from early-succession secondary forests, QASM= Quesungual agroforestry system from intermediate-succession secondary forests, YSF= early-succession secondary forests, MSF= intermediate-succession secondary forests, OSF= advanced-succession secondary forests, M*F*= Mature forest.

According to the Forward Selection procedure, only four of the fifteen physico-chemical soil attributes analyzed (Table 3) were significantly correlated with the total density of soil macrofauna (bulk density, $p \leq 0.04$; clay content, $p \leq 0.01$; soil moisture, p≤0.01; sand content, p ≤0.005) and were included in the RDA (Figure 4). This soil attributes accounted for 25% of the total variation of soil macrofauna density. Axis 1 accounted for 13.5% of the total variation of soil macrofauna data while Axis 2 explained 6.8%. Soil moisture was the attribute most important for contributing to the first component, while the textural attribute of soil was the second most important variable for explaining the total variance of data, as shown by the second component.

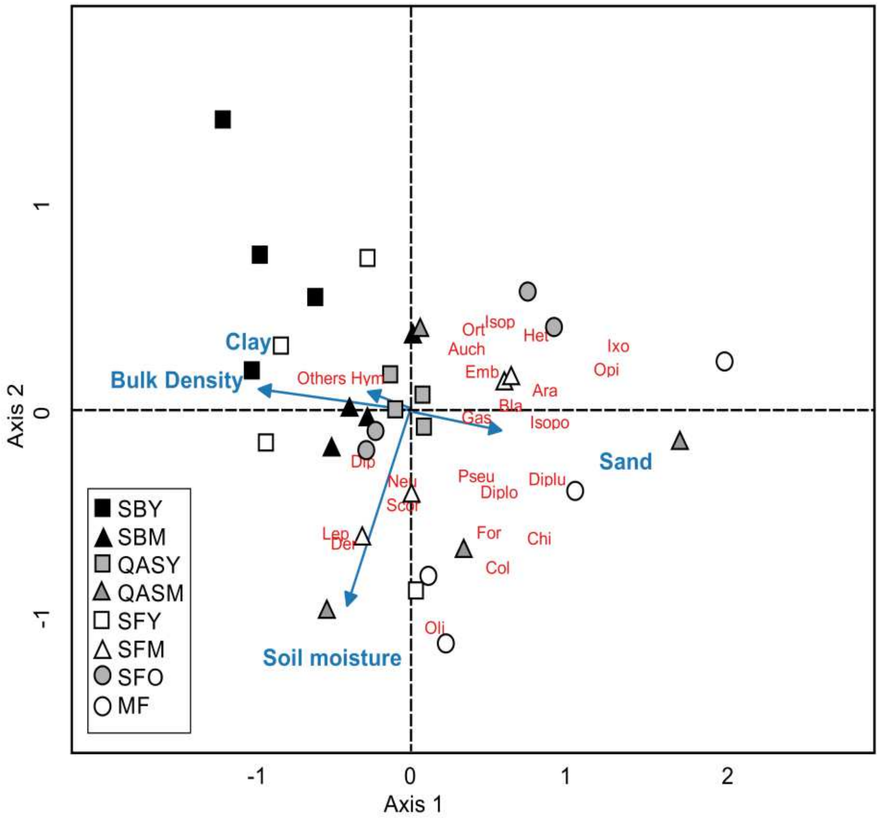

Fig. 4. Canonical redundancy analysis (RDA) with soil macrofauna density, soil physico-chemical and sampling sites in different land-uses in Alcântara County, Maranhão state, Brazil. Land uses: SBY= slash-and-burn agriculture from early-succession secondary forests, SBM= slash-and-burn agriculture from intermediate-succession secondary forests, QASY= Quesungual agroforestry system from early-succession secondary forests, QASM= Quesungual agroforestry system from intermediate-succession secondary forests, YSF= early-succession secondary forests, MSF= intermediate-succession secondary forests, OSF= advanced-succession secondary forests, M*F*= Mature forest. Taxa: Ara= Araneae, Auch= Auchenorryncha, Bla= Blattaria, Col= Coleoptera, Chi= Chilopoda, Der= Dermaptera, Dip= Diptera, Diplo= Dilopoda, Diplu= Diplura, Emb= Embioptera, Fer= Formicidae, Gas= Gastropoda, Lep= Lepidoptera, Het= Heteroptera, Isop= Isoptera, Isopo= Isopoda, Ixo= Ixodida, Neu= Neuroptera, Ort= Orthoptera, Oli= Oligochaeta, Opi= Opilionida, Other Hym= Others Hymenoptera, Pse= Pseudoscorpionida, Scor= Scorpionida.

Discussion

The development of agro-ecosystems that sustain productivity while promoting biodiversity is a challenge for improving rural livelihoods and achieving conservation goals (Velasquez et al., 2012). According to Brussaard et al. (2007), the conservation of soil macrofauna constitutes a significant aspect of agricultural sustainability. Indeed, soil macrofauna is more abundant and diverse in land use systems that conserve a structure similar to the original forest (Barros et al, 2002), while land use intensification for agriculture decreases soil macrofauna density and diversity (Barros et al., 2002; Mathieu et al., 2005; Bartz et al., 2014). Soil macrofauna abundance and richness found in our study area were consistent with other studies in the eastern Amazon (Rousseau et al., 2014; Triana et al., 2015).

Slash-and-burn agriculture had a strong negative impact on the richness and density of soil macrofauna (Rossi et al., 2010). The increase of soil surface temperature up to 400°C, the litter layer removal and the soil exposure to direct solar radiation (Matlack, 1993; Gimeno-García et al., 2004), lead to the loss of food sources, ecological niches and high mortality of soil organisms (Rossi et al., 2010). Instead, the Quesungual agroforestry system positively affected the richness and density of soil macrofauna, with values similar to the mature forest. Our results also confirm the ecological importance of fallow period as it influences the quantity and quality of resource available to the soil and the organisms that depend on it (Styger et al., 2007).

Quesungual is characterized by minimum soil disturbance, the continuous accumulation of litter and the presence of trees and shrubs in natural regeneration together with crop field (Pauli et al., 2011; Rousseau et al., 2013), conditions that favor the soil invertebrates (Menezes et al., 2009; Pauli et al., 2011). Although accelerating decomposition processes of tropical soils tends to diminish differences between soil management practices (Moura et al., 2014), the Quesungual system showed better soil attributes as it allowed greater deposition of biomass in the soil, similar to mature forest. The improved Organic Carbon of the soil is very important to conserve soil organisms, guarantee soil productivity and deliver soil ecosystem services (Moura et al., 2014; Celentano et al., 2016).

Although the defference in soil moisture and soil bulk density were not significant, their effect is narrowly associated with the best develop of soil macrofauna communities. Land use systems with capacity to maintain soil moisture and no increase in soil bulk density are very important to maintain soil organism populations (Celentano et al., 2016).

The macrofauna taxa that showed statistical differences between land use systems are those related to a stable environment, with high availability of food resources and a broad supply of ecological niches (Tews et al., 2004; Sayer et al., 2010). Predators (Araneae, Chilopoda and Pseudoscorpionida) were highly sensitive to changes in land use. Indeed, these groups are often related to conserved ecosystems with higher content of organic matter (Menezes et al., 2009; Vasconcellos et al., 2013; Moura et al., 2014), indicating the normal flow of energy and regular functioning of the trophic chain within the communities (Neutel et al., 2002; Moura et al., 2014).

The litter transformers and saprophages (organisms that feed on plant material in decomposition) are very important in the soil functions, especially nutrient cycling (Denich et al., 2004; Lavelle et al., 2006; Moura et al., 2014). The litter transformers such as Gastropoda are strongly associated with the quantity and quality of plant material deposited on the soil, preferring environments with greater quantity and diversity of plants (Rueda-Ramírez and Varela, 2016). While the saprophagous organisms, particularly diplopods are among the easiest to lose after a burning process and one of the most difficult to recover in restoration processes (Korobushkin et al., 2017).

High density Oligochaeta are commonly found in environments with largest soil moisture, less disturbed soil and the presence of organic soil cover. These organisms improve soil processes such as nutrient cycling, aggregation, water infiltration and aeration (Bartz et al., 2014).

The Quesungual system conserves macrofauna biodiversity and promotes soil fertility. According to Pauli et al. (2011) results in Central America, this system can also extend time of crop production (between 7 to 12 years), thus augmenting fallow periods and diminishing pressure throughout the forest. The Quesungual system has the potential to replace slash-and-burn agriculture in the eastern Amazon, with many ecological benefits. The widespread adoption of the Quesungual in Central America (Pauli et al., 2011; Rousseau et al., 2013) suggests that the smallholders found it well adapted to their needs. Preliminary results of cassava harvesting in Alcântara showed that the Quesungual system had similar yields to the slash-and-burn plots (data not presented) and that eight families involved in the project are interested in maintaining Quesungual testing plots independently. This social interest in agroecological transition must be confirmed, along with the ability of the Quesungual areas to restore soils and sustain demanding crops such as maize that assure food security in rural communities of the eastern Amazon.

Conclusions

The preliminary results of the use of the Quesungual agroforestry system in eastern Amazon suggest that this system represents a suitable alternative to replace slash-and-burn agriculture in small-scale family farming, with notable environmental gains. Soil macrofauna community was a very sensitive indicator of land use systems and it confirmed the ecological importance of fallow period as it influences the quantity and quality of resource available to the soil and the organisms that depend on it. Quesungual agroforestry system conserved similar density and richness of macrofauna in relation to mature forests allowing the normal flow of energy and regular functioning of the trophic chain within the communities, while slash-and-burn agriculture had strong negative impact on soil macrofauna community and soil quality as a consequence. The Quesungual agroforestry system maximized soil organic carbon accumulation and soil protection, suggesting a viable alternative to promote both soil biodiversity conservation and food security in eastern Amazon.

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SUPPLEMENTARY MATERIAL

Table A.1. Means of density (Ind/m^2) of the soil macrofauna by taxa and functional groups (average and standard errors) under different land uses in Alcântara County, Eastern Amazon.

Taxonomic Group	SBY*	SBM*	QASY*	QASM*	YSF*	MSF*	OSF*	MF*	F	*P-value*
Soil engineers										
Formicidae	**34.4 ±18.5 c**	**125.6 ±41.3 abc**	**155.2 ±14.1 abc**	**407.2 ±50.7 a**	**188 ±155.0 ab**	**74.4 ±21.3 bc**	**124 ±66.8 abc**	**304.8 ±101.5 ab**	**30.2**	**≤0.0001**
Isoptera	152 ±82.7	157.6 ±94.1	122.4 ±41.2	135.2 ±77.7	99.2 ±17.8	192.8 ±147.1	502.4 ±438.9	261.6 ±73.8	-	0.2487
Oligochaeta	**28 ±23.7 c**	**56.8 ±25.4 bc**	**70.4 ±16.6 abc**	**152 ±47.5 ab**	**115.2 ±67.3 ab**	**125.6 ±21.4 ab**	**91.2 ±44.4 abc**	**189.6 ±60.8 a**	**39.4**	**≤0.0001**
Saprophages										
Diptera	0 ±0	1.6 ±0.9	0.8 ±0.8	5.6 ±2.4	6.4 ±2.9	1.6 ±0.9	1.6 ±0.9	2.4 ±1.5	-	0.2788
Diplopoda	**0.8 ±0.8 b**	**11.2 ±4.8 ab**	**0.8 ±0.8 b**	**4.0 ±2.4 ab**	**0 ±0 c**	**4.8 ±2.0 ab**	**2.4 ±1.5 ab**	**16 ±4.5 a**	**17.6**	**≤0.0139**
Isopoda	0 ±0	2.4 ±1.5	0.8 ±0.8	4.0 ±4.0	0.8 ±0.8	0 ±0	3.2 ±1.3	16.8 ±8.4	-	0.1616
Litter Transformers										
Embioptera	0 ±0	0 ±0	4.0 ±2.0	3.2 ±1.3	1.6 ±0.9	1.6 ±0.9	2.4 ±1.5	2.4 ±1.5	-	0.2522
Gastropoda	**0.8 ±0.8 b**	**4.0 ±4.0 ab**	**4.0 ±0.8 ab**	**22.4 ±14.0 a**	**5.6 ±2.7 ab**	**12.8 ±8.5 ab**	**0.8 ±0.8 b**	**6.4 ±2.6 ab**	**20.6**	**≤0.0043**
Heteroptera	0.8 ±0.8	1.6 ±0.9	1.6 ±0.9	8.0 ±6.9	0.8 ±0.8	0.8 ±0.8	4.8 ±1.6	4.8 ±2.0	-	0.1461
Auchenorryncha	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	0.8 ±0.8	-	1.0000
Lepidoptera	0.8 ±0.8	2.4 ±0.8	1.6 ±1.6	4.0 ±2.0	0.8 ±0.8	1.6 ±1.6	1.6 ±0.9	4.0 ±3.0	-	0.7255
Orthóptera	1.6 ±1.6	0.8 ±0.8	3.2 ±1.3	5.6 ±3.5	0.8 ±0.8	1.6 ±1.6	3.2 ±2.2	4.0 ±2.0	-	0.6446
Omnivores										
Blattária	0 ±0	0.8 ±0.8	4.0 ±2.0	14.4 ±9.1	0 ±0	2.4 ±1.5	2.4 ±2.4	5.6 ±2.0	-	0.2528
Coleoptera	10.4 ±5.7	36.0 ±12.8	32.0 ±5.0	28.8 ±8.5	28.0 ±15.5	24.8 ±4.9	20.8 ±4.0	44.8 ±2.2	-	0.1535
Predators										
Araneae	**9.6 ±2.9 c**	**20.8 ±4.2 abc**	**24.0 ±7.4 abc**	**34.4 ±7.9 ab**	**9.6 ±5.3 c**	**21.6 ±3.7 abc**	**12.8 ±4.7 bc**	**44.8 ±12.4 a**	**36.3**	**≤0.0001**
Chilopoda	**3.2 ±2.2 d**	**6.4 ±1.8 cd**	**17.6 ±3.8 abc**	**44.8 ±18.2 ab**	**12.8 ±7.5 bcd**	**28.0 ±6.0 ab**	**15.2 ±1.5 abc**	**51.2 ±3.9 a**	**53.4**	**≤0.0001**
Dermáptera	0 ±0	0 ±0	0 ±0	3.2 ±3.2	2.4 ±1.5	0 ±0	0 ±0	1.6 ±0.9	-	0.7009
Diplura	0 ±0	2.4 ±1.5	2.4 ±1.5	14.4 ±9.2	7.2 ±1.5	12.8 ±3.6	17.6 ±5.3	14.4 ±6.7	-	0.2185
Neuroptera	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	0.8 ±0.8	0 ±0	2.4 ±1.5	-	0.2216
Opilionida	0 ±0	0.8 ±0.8	0 ±0	5.6 ±4.5	0 ±0	4.8 ±3.0	8.0 ±4.8	24.0 ±20.8	-	0.8380
Pseudoscorpionida	**1.6 ±1.6 ab**	**0.8 ±0.8 b**	**8.8 ±0.8 ab**	**14.4 ±5.9 a**	**3.2 ±2.2 ab**	**11.2 ±2.7 a**	**2.4 ±0.8 ab**	**13.6 ±5.4 a**	**25.3**	**≤0.0006**
Scorpionida	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	0 ±0	0.8 ±0.8	-	1.0000
Others										
Ixódida	**0 ±0 c**	**0.8 ±0.8 b**	**0 ±0 c**	**0.8 ±0.8 b**	**0.8 ±0.8 b**	**1.6 ±0.9 ab**	**4.8 ±2.7 a**	**0.8 ±0.8 b**	**355.9**	**≤0.0001**
Others Hymenoptera	0.8 ±0.8	0.8 ±0.8	0.8 ±0.8	0.8 ±0.8	1.6 ±0.9	0 ±0	0 ±0	0.8 ±0.8	-	0.9998

Means with different letter indicate significant differences according to the Tukey test (p≤0.05).

* SBY= slash-and-burn agriculture from early-succession secondary forests, SBM= slash-and-burn

agriculture from intermediate-succession secondary forests, QASY= Quesungual agroforestry system from early-succession secondary forests, QASM= Quesungual agroforestry system from intermediate-succession secondary forests, YSF= early-succession secondary forests, MSF= intermediate-succession secondary forests, OSF= advanced-succession secondary forests, M*F*= Mature forest.

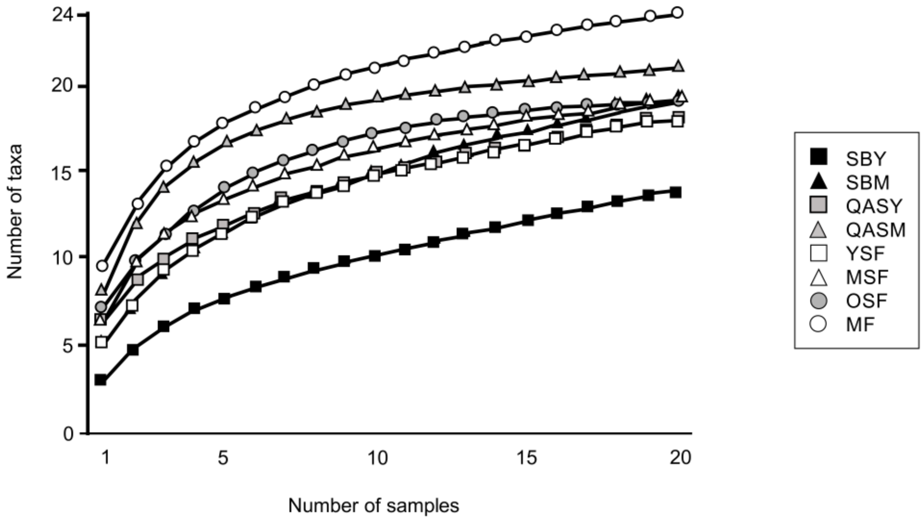

Fig.A.1. Taxa accumulation curve of soil macrofauna under different land uses in Alcântara County, Eastern Amazon. Where, SBY= slash-and-burn agriculture from early-succession secondary forests, SBM= slash-and-burn agriculture from intermediate-succession secondary forests, QASY= Quesungual agroforestry system from early-succession secondary forests, QASM= Quesungual agroforestry system from intermediate-succession secondary forest, YSF= early-succession secondary forests, MSF= intermediate-succession secondary forests, OSF= advanced-succession secondary forests, M*F*= Mature forest.