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INTERACTIONS AMONG LEGUMINOUS TREES, CROPS AND WEEDS IN A NO-TILL ALLEY CROPPING SYSTEM

SÃO LUÍS

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DEDICO

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“O sucesso nasce do querer, da determinação e persistência em se chegar a um objetivo. Mesmo não atingindo o alvo, quem busca e vence obstáculos, no mínimo fará coisas admiráveis."

José de Alencar

SUMÁRIO

CAPITILO II - INTERACTIONS AMONG LEGUMINOUS TREES, CROPS AND WEEDS IN A NO-TILL ALLEY CROPPING SYSTEM

CAPITULO I

I - Introdução Geral

A região do trópico úmido apresenta, predominantemente, solos derivados de rochas sedimentares clásticas. Estes solos possuem estrutura frágil e baixa fertilidade natural; são susceptíveis à coesão, portanto, não alcançam altas produtividades agrícolas. Além disso, o clima da região apresenta altas temperaturas e chuvas acentuadas nos seis primeiros meses do ano, características estas que exigem condições particulares de manejo do solo. Aliada a essa problemática, o modelo de produção agrícola dominante na região é a agricultura itinerante, que consiste no corte e queima da vegetação, seguido do cultivo da lavoura e pousio (descanso) da área.

A regeneração da capoeira requer um longo período de descanso da área cultivada. Porém, o aumento da densidade populacional encurta o período de pousio e ameaça a estabilidade do sistema (VEGA et al., 2005). Nestas condições, existem grandes desvantagens porque a biodiversidade é afetada e as espécies mais resistentes dominam o ecossistema. Adicionalmente esse sistema contribui para o aumento da produção de gases do efeito estufa (ARAÚJO et al., 2008). Encontrar uma alternativa para essa agricultura torna-se necessário por duas razões: primeiro pela necessidade urgente de aumentar a produtividade agrícola e, segundo pela necessidade imediata de reduzir os impactos ambientais das queimadas (AGUIAR et al., 2010a). Em muitos casos, diversos produtores tentam substituir esse sistema pelo uso da gradagem e adubos sintéticos, o que apenas agrava o quadro de degradação ambiental, sem aumentar a produtividade agrícola. Estas problemáticas aliadas às condições locais de solo e clima afetam negativamente a produção de alimentos.

Para reverter esse cenário, é de grande importância a adoção de práticas agrícolas sustentáveis que levem em consideração tanto a questão da alta produtividade quanto as questões ambientais. Entre essas práticas podemos citar o plantio direto na palha e o uso de sistemas agroflorestais (LAL, 2004).

O plantio direto na palha consiste no plantio sem o preparo do solo com grade ou arado logo após a colheita, ou seja, o plantio é realizado sobre a fitomassa da cultura anterior. Esse sistema é caracterizado pela rotação de culturas e permanência da palha na superfície do solo, que posteriormente é revolvida apenas na fileira de deposição das sementes e fertilizantes (REIS et al., 2007). Essa forma de plantio é muito utilizada em regiões em que as chuvas são suficientes para produção de duas colheitas (verão e inverno). No Estado do Maranhão, esse sistema não seria totalmente adequado, uma vez que o peródo de seis meses de chuva é seguido por um periodo de estiagem, impossibilitando a produção suficiente de palha para a cobertura do solo.

O cultivo em aléias é um sistema agroflorestal, que envolve o plantio de árvores ou arbustos, de preferência leguminosas (GILLESPIE et al., 2000). As árvores podem ser periodicamente podadas e seus ramos adicionados às entrelinhas onde a cultura de interesse econômico é plantada. O cultivo em aléias pode possibilitar o aporte de resíduos vegetais ricos em nitrogênio, que podem ser utilizados na adubação verde, além de oferecer os benefícios do efeito da cobertura morta no solo.

Levando em consideração as peculiaridades do tropico úmido, pesquisadores de Agroecologia da Universidade Estadual do Maranhão recomendam um agrossistema denominado de “plantio direto na palha de leguminosas cultivadas em aléias” (MOURA et al., 2009). Esse sistema combina as vantagens do “plantio direto na palha” com os benefícios do “cultivo em aléias”.

Características desejáveis desse sistema incluem o aporte contínuo de resíduos vegetais de alta e baixa qualidade pelas árvores do sistema, a manutenção ou aumento da matéria orgânica do solo, o aumento da capacidade de ciclagem de nutrientes (FERRAZ JÚNIOR, 2004), e redução da incidência de plantas daninhas devido ao efeito da cobertura do solo (ARAUJO et al., 2007). Além da supressão de plantas daninhas através da cobertura, observam-se também interações entre as plantas através de sinais químicos, denominada alelopatia. Essa interferência pode ocorrer na inibição da germinação da semente, diminuindo o crescimento, causando danos na planta ou mesmo a morte desta na presença de outra espécie (OYUN, 2006). Recentemente muitos casos de diminuição do rendimento das culturas solteiras e em sistemas agroflorestais tem sido atribuído a efeitos alopáticos (EL-KHAWAS e SHEHATA, 2005). Problemas associados à alelopatia são observados tanto em monoculturas como em sistemas mais diversificados como constatado por OYUN, (2006) e AGUIAR et al., (2010b).

Nesse contexto, a utilização de sistemas mais diversificados, exige atenção na escolha das leguminosas a serem implantadas na área, pois, devem-se considerar as interações tanto benéficas quanto maléficas entre as plantas dentro desse sistema. Além das competições por água, luz e nutrientes entre as culturas comerciais e as leguminosas, deve-se levar em consideração os efeitos alelopáticos que podem afetar o crescimento das culturas implantadas, como o algodão e o milho, além das plantas daninhas.

O objetivo deste trabalho foi avaliar as interações biofísicas entre leguminosas arbóreas, plantas daninhas e as culturas do algodão e do milho em um sistema plantio direto na palha de leguminosas cultivadas em aléias.

II - Referencial teórico

1 Algodão colorido

O algodão colorido (*Gossypium hirsutum* L*)* é uma fibra pigmentada naturalmente que cresce em tons de verde e marrom. Seu cultivo remonta a cerca de 2700 a.C., na Índia, Paquistão, Egito e Peru (VREELAND et al., 1999). Depois de ter desaparecido por cerca de um século, o algodão colorido reapareceu sendo chamado de "eco-friendly - algodão amigo do meio ambiente" no início dos anos 90 (KHAN et al., 2010). O algodão colorido é inerentemente inferior ao algodão branco em vários aspectos, como a baixa produtividade, possui fibras curtas, grossas e fracas, impossibilitando-o de ser maquinável, além não possuir cor uniforme (MURTHY, 2001). Porém, resiste melhor às pragas, portanto, reduz a aplicação de agrotóxico, o que leva à diminuição da poluição (LEE, 1996). Além do uso destas variedades de algodão eliminarem as etapas de branqueamento e o tingimento.

Apesar de suas características serem inferiores ao branco, seu ressurgimento está associado principalmente às questões ambientais. De todo o inseticida usado mundialmente, aproximadamente 23% é utilizado por produtores de algodão para combater pragas como o bicudo. Estes agrotóxicos prejudicam tanto os trabalhadores quanto o meio ambiente, pois infiltram no solo, atingem águas subterrâneas, rios e riachos, matam peixes, além de contaminar o gado (KHAN et al., 2010). Para dar cores ao algodão de fibra branca, durante o processo de branqueamento e tingimento, as fábricas utilizam regularmente diversas substâncias tóxicas, incluindo metais pesados. A água destas unidades é uma das principais fontes de poluição de alimentos e água para consumo humano e meio ambiente. Muitos destes produtos químicos são cancerígenos e podem causar alergias, erupções cutâneas e outros problemas relacionados com a saúde

(DUTT et al., 2004). Por isso, atualmente muitas pessoas preferem usar roupas feitas a partir do algodão colorido, que é livre de substâncias tóxicas. Essa procura por produtos sem substâncias químicas tem incentivado muitos produtores e está levando à revitalização da cultura do algodão colorido (DUTT et al., 2004).

2 Milho

O milho (*Zea mays* L.) é uma planta da família gramineae, com o centro de origem mais provável no México Meridional, situado na América Central. **Essa cultura se** constitui em um dos mais importantes cereais cultivados e consumidos no mundo. É uma cultura de grande importância econômica no Brasil, tanto na agricultura familiar, quanto nos grandes latifúndios. Trata-se de um alimento rico em carboidratos, de considerável valor energético; é também fonte de óleo, fibras, vitaminas E, B1, B2 e ácido pantotênico, além de alguns minerais, como o fósforo e o potássio (FARINELLI et al., 2003).

Por causa da sua grande diversidade de aplicações, tanto na alimentação humana quanto na alimentação animal, assume relevante papel socioeconômico, além de constituir-se em indispensável matéria-prima impulsionadora de diversificados complexos agroindustriais (FANCELLI e DOURADO NETO, 2000).

Segundo ARCE et al. (2005), enquanto matéria-prima para a indústria, o milho possibilita a obtenção de cerca de 600 subprodutos destinados à alimentação animal e humana, além de ser componente de produtos gerados pela indústria química, têxtil, de mineração, mecânica e outras.

Essa gramínea pertence ao grupo de plantas com metabolismo fotossintético do tipo C4, que se caracteriza pelo elevado potencial produtivo. Entre as plantas C4, o milho está no grupo de espécies com maior eficiência de uso da radiação solar

(BERGAMASCHI et al., 2004), e essa é uma das características que torna a cultura muito bem adaptada as condições do tropico úmido.

3 Plantas daninhas

No manejo das plantas daninhas, o princípio da prevenção deve ser privilegiado. Devem-se priorizar plantas com alta produção de palha e com ação de efeito alelopático. Além dos efeitos químicos, oriundos da palha, os efeitos físicos, contribuem para o controle das plantas daninhas (VAZ DE MELO et al., 2007).

De acordo com MACLEANA et al. (2003), o sistema em aléias favorece algumas estratégias para o controle de plantas daninhas: a adubação verde, pois a decomposição dos resíduos aplicados no solo melhora os indicadores físico-químicos do solo, alterando a composição das plantas daninhas e a habilidade da cultura para competir com elas; a cobertura morta, pois esta pode impedir a germinação de sementes de plantas daninhas; o sombreamento, já que diminui a incidência de luz na área durante a estação de crescimento das árvores, pode reduzir a abundância das espécies sensíveis à sombra. Ainda, pode-se citar o controle através da alelopatia, no qual há produção de substâncias químicas e redução da quantidade de plantas daninhas da área (SOUZA FILHO e ALVES, 2000). Porém, é importante destacar que esses compostos químicos liberados na decomposição das plantas são muitos específicos.

No cultivo do algodão o manejo correto de plantas daninhas é fundamental para o sucesso na produção. Quando não manejadas de modo adequado, essas plantas podem causar redução na produtividade, e algumas delas podem prejudicar a qualidade do produto colhido, aumentando custos e reduzindo o valor da fibra (FREITAS et al., 2002).

No caso do milho, a redução do rendimento da cultura devido à competição estabelecida com as plantas daninhas varia de 12 até 100%, em função da espécie, do grau de infestação, do tipo de solo, das condições climáticas reinantes no período, além do estádio fenológico da cultura (KOZLOWSKI, 2002).

Portanto, é de extrema importância, adotar práticas que diminuam a densidade populacional das plantas daninhas, tendo atenção no momento da seleção das espécies que servirão como cobertura para que se obtenha êxito no controle das ervas mais agressivas e para que a cultura principal mostre seu desempenho potencial.

4 Plantio direto

O plantio direto constitui um sistema eficiente no controle de erosão e tem sido utilizado cada vez em maior escala, principalmente em áreas com culturas anuais e sujeitas à ação dos processos erosivos. Essa forma de manejo do solo é considerada uma alternativa para reduzir custos e quantidade de mão de obra do campo em relação ao plantio convencional. Esse sistema tenta assegurar a sustentabilidade do uso agrícola dos solos (SCHERER, 2007).

A adoção e implementação bem sucedida do plantio direto é extremamente dependente do conhecimento do agricultor e da tecnologia envolvida no sistema. Além disso, o sucesso do plantio direto em uma determinada área depende das condições climáticas locais (CAVALIERI et al., 2009).

Nesse sistema, adota-se o uso de máquinas próprias e o controle de plantas daninhas, quando necessário, é realizado com a aplicação de herbicidas. Segundo SILVA et al. (1999), algumas características desejáveis devem ser observadas nas espécies para que estas sejam cultivadas nesses sistema: produzir grande quantidade de matéria seca, ser resistentes ao ataque de pragas e doenças, possuir sementes uniformes e de bom poder germinativo, ter exigência relativamente baixa quanto ao preparo e fertilidade do solo, ser de rápido crescimento, fácil manejo e possuir sistema radicular profundo.

O solo sob plantio direto apresenta, principalmente na sua camada superficial, melhor estrutura, maior taxa de infiltração de água, maiores teores de matéria orgânica e maior atividade microbiana (SCHERER, 2007). Adicionalmente esse sistema pode ser considerado uma atividade com potencial para seqüestrar carbono (SIQUEIRA NETO et al., 2009).

5 Cultivo em aléias

O cultivo em aléias é um dos mais simples sistemas agroflorestais que combina em uma mesma área espécies arbóreas, preferencialmente leguminosas, em fileiras simples ou duplas (GILLESPIE et al., 2000) e culturas anuais de interesse econômico. As leguminosas são plantadas com espaçamento de 2 a 6 metros entre limhas. Os ramos das leguminosas podem ser periodicamente cortados à altura que variam de 0,1 a 0,5 metros, e serem adicionados às entrelinhas das culturas de interesse econômico, servindo como cobertura morta e adubo verde (KANG et al., 1990).

O sistema em aléias promove efeitos benéficos tanto ambiental quanto economicamente. Ambientalmente por aumentar o tempo que determinado volume de água permanece no solo (MILLER e PALLARDY, 2001); aumentar a atividade dos microorganismos, proteger a superfície do solo contra o impacto das gotas da chuva, diminuir a temperatura na superfície do solo, diminuir a quantidade de plantas daninhas (KANG, 1997) tanto por efeitos alelopáticos quanto pelo efeito supressivo da cobertura (ALLEN et al., 2004). Além disso, o componente arbóreo do sistema agroflorestal pode, também, atuar a longo prazo como um dreno de carbono (OELBERMANN et al., 2004), diminuindo a quantidade desse elemento na atmosfera. Economicamente por diminuir a aplicação de insumos externos, pois as árvores são capazes de capturar e reciclar nutrientes dos horizontes mais profundos do solo e, portanto, pode ajudar na melhoria da eficiência do uso de nutrientes (ALLEN et al., 2004), além da adubação verde advinda da fitomassa destas árvores.

Um dos mais difundidos problemas desse modelo é a competição por luz, água (GILLESPIE et al., 2000) e nutrientes entre culturas as anuais e as leguminosas do sistema. Porém, essas leguminosas são capazes de afetar as culturas implantadas também através da liberação de aleloquímicos (WESTON, 1996). Nesse contexto, o conhecimento das interações entre as leguminosas arbóreas e as culturas anuais é de grande importância para o manejo dos sistemas agroflorestais (SANTOS et al., 2010).

As espécies de leguminosas recomendadas para o uso nesse sistema de cultivo devem apresentar características de rápido crescimento, adaptação às condições locais (solo e clima); possuir sistema radicular profundo, com mínimas raízes na superfície do solo para minimizar a concorrência com a cultura principal; fácil estabelecimento no campo (HODGE et al., 1999); possuir alta capacidade de rebrota; alta produção de biomassa; fazer fixação biológica de nitrogênio (N) e possuir altos teores de N nos tecidos (KANG et al., 1990).

6 Plantio direto na palha de leguminosas cultivadas em aléias

Na tentativa de substituição do modelo de corte e queima por um modelo mais sustentável que leva em consideração as condições específicas do trópico úmido, o plantio direto na palha de leguminosas cultivadas em aléias pode ser uma alternativa viável, pois agrupa os benefícios do plantio direto na palha com as utilidades do sistema de cultivo em aléias. Nesse sistema são plantadas árvores ou arbustos em linhas simples ou múltiplas. A distância entre as fileiras é determinada pela quantidade de biomassa requerida para o manejo do solo (MOURA et al., 2009).

Nesta forma de cultivo, as leguminosas são, geralmente, selecionadas por promoverem o crescimento de culturas estabelecidas (MOURA et al., 2009). Essas leguminosas são periodicamente podadas e seus ramos aplicados entre as fileiras. Esse sistema promove a cobertura do solo e a manutenção ou o aumento dos nutrientes na zona da raiz de culturas implantadas (MOURA et al., 2010). Essas leguminosas estão adaptadas para crescer no período de seca e produzir resíduos de alta qualidade.

O plantio direto na palha de leguminosas cultivadas em aléias oferece para os pequenos agricultores a grande vantagem de reunir no mesmo espaço e tempo a produção de alimentos e a regeneração da fertilidade do solo (MOURA et al., 2010), pois essa junção não é possível no sistema de corte e queima.

7 Efeito alelopático da cobertura de leguminosas

RICE, (1984) definiu alelopatia como o efeito de uma planta em outra planta por meio da liberação de compostos químicos para o ambiente. Esta definição inclui tanto efeitos estimuladores quanto inibidores, dependendo da concentração dos compostos. As culturas de cobertura contêm altos níveis de aleloquímicos (KRUIDHOF et al., 2009), que podem influenciar tanto as plantas daninhas como as culturas comerciais. Quando essas culturas de cobertura são aplicadas no solo, tanto por exsudação quanto por decomposição dos resíduos, os aleloquímicos provenientes destas coberturas têm o potencial de influenciar o ciclo de vida das plantas próximas, dependendo da quantidade e persistência da substância química (PUTNAM, 1983). GOLDFARB et al. (2009) e ALMEIDA, (1991), mencionam que as substâncias alelopáticas provocam redução da germinação, falta de vigor vegetativo, morte das plântulas, clorose das folhas, redução do perfilhamento e atrofiamento ou deformação das raízes.

Leguminosas arbóreas são comumente utilizadas em sistemas agroflorestais para a cobertura do solo e adubação verde. Essas plantas podem exercer efeitos alelopáticos nas culturas implantadas. Entre essas leguminosas podemos citar a acácia (*Acacia mangium*), gliricídia (*Gliricidia sepium*), leucena (*Leucaena leucocephala*) e sombreiro (*Clitoria fairchildiana*).

A *Acacia mangium* é uma leguminosa originária da Austrália e da Malásia, conhecida popularmente pelo nome de acácia australiana, que se adaptou muito bem às condições de solo e clima tropical brasileiro (LUZ et al., 2010). Algumas espécies do gênero acácia tem mostrado efeitos alelopáticos em feijão, rabanete e alface (CARBALLEIRA e REIGOSA, 1999). DIXON e SUMNER, (2003) afirmaram que todas as classes conhecidas de terpenóides foram notificadas nessa leguminosa e se constituem no segundo maior grupo (depois dos fenólicos) de metabólitos secundários implicados na alelopatia das plantas de acácia (INDERJIT et al., 1999).

A gliricídia possui seu centro de origem na América Central (México) (NAZLI et a.l, 2008). Os primeiros relatos da possibilidade do uso da gliricídia no controle das plantas daninhas ocorreram na década de 1980 (LINHARES, 2008). De acordo com RAMAMOORTHY e PALIWAL, (1993), foram identificadas pelo menos 15 substâncias tóxicas na parte aérea da gliricídia que podem atuar como substâncias alelopáticas. Segundo OBANO, (1987), a palhada de gliricídia não tem efeito alelopático sobre o milho ou feijão, mas diminui significativamente a população de algumas espécies de plantas daninhas.

A leucena (*Leucaena leucocephala*) é uma leguminosa exótica, originária do México e é encontrada em toda a região tropical (SCHERER, 2005). Entre os inúmeros compostos existentes na leucena, a mimosina é considerada o principal agente alelopático. Segundo BUDELMAN (1988), a leucena promove o controle de plantas daninhas e esse efeito ocorre devido à presença de aleloquímicos na parte aérea da planta. De acordo com PRATES et al., (2000) o extrato aquoso da leucena, obtido com água à temperatura ambiente, quando aplicado ao solo não causa problema de fitotoxicidade para as plantas de milho. Segundo VESTANA et al. (2001), diversas partes da leucena acumulam quantidades significativas do composto mimosina que age inibindo a germinação e o crescimento de diversas plantas (JACOBI et al., 1991; VESTENA et al., 2001).

O sombreiro é uma espécie nativa e está amplamente distribuída em várias regiões do Brasil (MAGISTRALI et al., 2009). São poucos os trabalhos já realizados sobre as potencialidades alelopáticas dessa planta e ainda não se sabe com exatidão qual ou quais as substâncias químicas envolvidas na sua atividade alelopática. É possível que a presença de grupos fenólicos minimize o efeito tóxico de algum outro tipo de substância produzida pelo sombreiro (SOARES et al., 2002). Por ser uma espécie nativa, seu caráter alelopático é menos agressivo que as plantas exóticas (HIERRO e CALLAWAY, 2003).

Vários trabalhos têm sido realizados para avaliar os efeitos alelopáticos dessas espécies de plantas leguminosas, porém a grande maioria é em nível laboratorial e não leva em consideração as interações que acontecem no sistema. Trabalhos de campo são necessários, pois simulam com maior precisão as relações que ocorrem entre as plantas por abrangerem os mecanismos de interferência que acontecem na natureza.

Referências bibliográficas

AGUIAR, A. C. F.; BICUDO, S. J.; COSTA SOBRINHO, J. R. S.; MARTINS, A. L. S.; COELHO, K. P.; MOURA, E. G. Nutrient recycling and physical indicators of an alley cropping system in a sandy loam soil in the pre-Amazon region of Brazil. **Nutr Cycl Agroecosyst,** v. 86, p. 189–198, 2010a.

AGUIAR, A. C. F., FREITAS, I. C., CARVALHO, C., MONROE, P. H. M., MOURA, E.G.. Efficiency of an agrosystem designed for family farming in the pre-Amazon region. **Renewable Agriculture and Food Systems,** v 26, n.1, p. 24–3, 2010b.

ALLEN, S.C., JOSE, S., NAIR, P.K.R., BECKY, B.J., KIZZA, P.N., RAMSEY, C.L. Safety-net role of tree roots: evidence from a pecan (Carya illinoensis K. Koch)-cottonn(Gossypium hirsutum L.) alley cropping system in the southern United States. For. **Ecol. Manage,** v. 192, p 395–407, 2004.

ALMEIDA, F.S. Efeitos alelopáticos de resíduos vegetais. **Pes. agropec. bras,** Brasília, v. 26, n. 2, p.221-236, 1991.

ARAUJO, J.C; MOURA, E.G; AGUIAR, A.C.F.; MENDONÇA, V.C.M. Supressão de plantas daninhas por leguminosas anuais em sistema agroecológico na pré-amazônia. **Planta Daninha**,Viçosa-MG, 25(2), 267-275, 2007.

ARAÚJO, A.; FERRAZ JUNIOR, A. S. L.; MOURA, E. G.; AGUIAR, A.C.F. Comportamento de dois genótipos de milho cultivados em sistema de aléias preestabelecido com diferentes leguminosas arbóreas. **Bragantia,** Campinas, v.67, n.4, p.875-882, 2008.

ARCE, H.; ARIAS, E. R. A.; PEREIRA, F. A. R.; SCHEEREN, B. R. Estimativa do impacto da adoção de cultivares melhoradas de milho para sustentabilidade das pequenas propriedades rurais de mato grosso do sul. **Ensaios e ci.,** Campo Grande, v. 9, n. 2, p. 337-352, 2005.

BERGAMASCHI, H; DALMAGO, G. A.; BERGONCI, J. I.; BIANCHI, C.A.M.; MÜLLER, A. G.; COMIRAN, F.; HECKLER, B. M.M. Distribuição hídrica no período crítico do milho e produção de grãos**. Pesq. agropec. bras**, Brasília, v.39, n.9, p.831-839, set. 2004.

BUDELMAN, A. The performance of the leaf mulches of *Leucaena leucocephala*, *Flemingia macrophylla* and *Gliricidia sepium* in weed control. **Agroforestry Systems**, v.6, p.137-145, 1988.

CARBALLEIRA, ALEJO; REIGOSA, M. J.Effects of natural leachates of Acacia dealbata Link in Galicia(NW Spain). **Bot. Bull. Acad. Sin,** v.40, p.87-92, 1999.

CAVALIERI, K.M.V.; SILVA, A.P.; TORMENA, C.A.; LEAO,T. P.; DEXTER, A. R.; KANSSON, I.H. Long-term effects of no tillage on dynamic soil physical properties in a Rhodic Ferrasol in Parana, Brazil. **Soil & Tillage Research,** v.103, p.158–164, 2009.

DIXON, R. A.; SUMNER, L. W. Legume natural products: understanding and manipulating complex pathways for human and animal health. **Plant Physiol,** v. 131, n. 6, p. 878-885, 2003.

DUTT, Y.; WANG, X. D. ; ZHU, Y. G. ; LI ,Y. Y. Breeding for high yield and fibre quality in coloured cotton. **Plant Breeding,** v.123, p. 145 -151, 2004.

EL-KHAWAS, S. A; SHEHATA, M.M. The allelopathic potentialities of acácia nilótica and Eucalyptus rostrata on monocot (zea mays L.) and Dicot (phaseolus vulgaris L.) plants. **Biotechnology**, v.4, n.1,p. 23-34, 2005.

FANCELLI, A. L.; DOURADO NETO, D**.** Produção de milho. **Guaíba Agropecuária**, v. 34, p. 360, 2000.

FARINELLE, R.; PENARIO,F. G.; BORDIN, L.; COICEV, L.; FORNASIERI FILHO, D.Desempenho Agronômico de cultivares de milho nos períodos de safra e safrinha. **Bragantia**. v.62, n.2, 2003.

FERRAZ JUNIOR, A.S.L. O cultivo em aléias como alternativa para a produção de alimentos na agricultura familiar do trópico úmido. In: MOURA, E.G. (Ed.).**Agroambientes de transição: entre o trópico úmido e o semi-árido do Brasil**, São Luís: Universidade Estadual do Maranhão, v.3, p. 71-100, 2004.

FREITAS, R.S.; BERGER, P.G.; FERREIRA, R.; CARDOSO, A.A.; FREITAS, T.A.S.; PEREIRA,C.J. Interferência de plantas daninhas na cultura de algodão em sistema de plantio direto. **Planta Daninha**, Viçosa-MG, v.20, n.2, p.197-205, 2002.

GOLDFARB, M.; PIMENTEL, L. W.; PIMENTEL, N.W. Alelopatia: relações nos agroecossistemas.**Tecnol. & Ciên. Agropec.** v.3, n.1, p.23-28, fev. 2009.

HIERRO, J. L.; CALLAWAY, R. M. Allelopathy and exotic plant invasion. **Plant and Soil,** v. 256, p. 29–39, 2003.

HODGE, S., GARRETT, H.; BRATTON, J. Alley Cropping: an Agroforestry Practice. **USDA Natural Resources Conservation Service**, 1999.

INDERJIT, D. e KEATING, K. M. M. Allelopathy: principles, procedures, processes, and promises for biological control. **Academic Press**., v. 67, p. 458 p., 1999.

JACOBI, U.S., FERREIRA, A.G. Efeitos alelopaticos de Mimosabimucronata (DC) sobre espécies cultivadas. **Pesq. Agropec. Bras**., v. 26, p. 935 –943, 1991.

KANG, B.T. Alley cropping- soil prodictivity and nutrient recycling. **Intenational Forest ecology and management**., v. 91, p. 75-82, 1997.

KANG, B.T.; REYNOLDS, L.; ATTA-KRAH, A.N. Alley Farming. **Advances in Agronomy,** New York, v .43, p. 315-359, 1990.

KHAN, A. I. ; AWAN, F.S.; SADIA, B. Rashid mehmood rana and iftikhar ahmad khan. Genetic diversity studies among coloured cotton genotypes by using rapd markers**. Pak. J. Bot**., v. 42, n.1, p. 71-77, 2010.

KOZLOWSKI, L. A. Período crítico de interferência das plantas daninhas na cultura do milho baseado na fenologia da cultura. **Planta Daninha**, v. 20, n. 3, p. 365-372, 2002.

KRUIDHOF , H. M.; BASTIAANS, L; KROPFF, M. J. Cover crop residue management for optimizing weed control. **Plant Soil**, v.318:, p.69–184, 2009.

LAL, R. Soil carbon sequestration impacts on global climate change and food security, **Science,** v. 304 ,p. 1623–1629, 2004.

LEE, J. A new spin on naturally colored cottons. **Agricultural Research Magazine**, v. 44, p. 20-21, 1996.

LINHARES, E. L. R.. **Densidade de plantio da gliricídia em consorcio com milho para controlar plantas daninhas.** 2008. Tese (Doutor em Agronomia: Fitotecnia) Universidade Federal Rural do Semi-Árido. 2008.

LUZ, S.M.; SOUZA FILHO, A.P.S.; GUILOHN, G.M.S.P.; VILHENA, K.S.S. Allelopathic Activity of Chemical Substances Isolated from Acacia mangium and Its Variationsin Function of pH. **Planta Daninha**, Viçosa-MG, v. 28, n. 3, p. 479-487, 2010.

MACLEANA R.H.; LITSINGER, J.A.; MOODYC, K; WATSON,A.K.; LIBETARIO, E.M. Impact of *Gliricidia sepium* and *Cassia spectabilis* hedgerows on weeds and insect pests of upland rice.Agriculture, **Ecosystems and Environment.** v.94, p.275–288, 2003.

MAGISTRALI, I. C.; ANJOS, N.; SOUZA, R. M.; DUARTE, C. L. Ocorrência e infestação de euphalerus clitoriae burckhardt & guajará, 2000 (hemiptera: psylloidea) em árvores de sombreiro (clitoria fairchildiana howard) utilizadas na arborização urbana de viçosa-mg. **REVSBAU**, Piracicaba – SP, v.4, n.4, p.100-110, 2009

MILLER, A.W., PALLARDY, S.G. Resource competition acrosscrop–tree interface in a maize–silver maple alley cropping stand in Missouri**. Agriculture, Ecosystems and Environment** v.105, p.163–172, 2005.

MOURA, E.G.; SERPA, S.S.; SANTOS, J. G. D.; COSTA SOBRINHO, J. R. S.; AGUIAR, A. C. F.. Nutrient use efficiency in alley cropping systems in the Amazonian periphery. **Plant Soil**, v. 335, n 1-2, 363-371.2010.

MOURA, E.G.; ARAÚJO, J.R.G.; MONROE, P.H.M.; NASCIMENTO, I.O.; AGUIAR, A.C.F. Patents on periphery of the Amazon rainforest. **Recent Patents on Food, Nutrition & Agriculture**, v. 1, p. 142-148, 2009.

MURTHY, M. S. S. Never say dye: the story of coloured cotton. **Resonance**, v.29, p.35, 2001.

NAZLI, R.; AKHTER, M.; AMBREEN, S.; SOLANGI A. H.; SULTANA, N. Insecticidal, nematicidal and antibacterial activities of gliricidia sepium. **Pak. J. Bot**., v. 40, n 6, 2625-2629, 2008.

OELBERMANN, M.; VORONEY, R. P.; GORDON, A.M. Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and southern Canada. Agriculture. **Ecosystems and Environment,** v .104, p. 359–377, 2004.

OBANDO, L. Potencial alelopatico de Gliricidia septum (Jacq.) Walp. sobre los cultivos de maiz y frijol y las malezas predominantes (abstract) In:WASHINGTON, D.; GLOVER, N.; BREWBAKER, J.L. (Eds.). *Gliricídia sepium* (Jacq.) Walp., management and improvement, Turrialba: **Nitrogen Fixing Tree Association (NFTA**), p.59-60, 1987.

OYUN, M.B. Allelopathic Potentialities of *Gliricidia sepium* and *Acacia auriculiformis* on the Germination and Seedling Vigour of Maize (*Zea mays L.*). **American Journal of Agricultural and Biological Science,** v.1, n.3, p.44-47, 2006.

PRATES,H. T.; PAES, J. M. V.; P. N. M.; PEREIRA FILHO, I.; MAGALHÃES, A. P. C. Efeito do extrato aquoso de leucena na germinação e no desenvolvimento do milho**. Pesq. agropec. bras.** Brasília ,v.35, n.5, p. 167-179, 2000.

PUTNAM, A. R.; DEFRANK. J. Use of phytotoxic plant residues forselective weed control. **Crop Prot,** v. 2, p. 173–181, 1983.

RAMAMOORTHY, M; PALIWAL, K. Allelopathic compounds of Gliricidia sepium (Jacq) Kunth ex Walp. And its effect on Sorghum vulgare L.. **Journal of Chemical Ecology**, v.19, n.8, p.1691-1701, 1993.

REIS, G. N. ; FURLANI, C. E. A.; SILVA, R. P.; GERLACH, J. R.; CORTEZ, J. W.; GROTTA, D. C. C. Decomposição de culturas de cobertura no sistema plantio direto, manejadas mecânica e quimicamente**. Eng. Agríc.** V.27, n.1 .jaboticabal, 2007.

RICE, E. L. **Allelopathy**. 2. ed. Orlando: Academic, p -422 . 1984.

SANTOS, C. C.; Levy SILVA, G.; SILVA, G. C.; FERRAZ JUNIOR, A. S. L. Alelopatia entre leguminosas arbóreas e feijão-caupi. **Scientia Agraria,** Curitiba, v.11, n.3, p.187-192, 2010.

SCHERER L. M.; ZUCARELI, V.; ZUCARELI, C. A.; FORTES, A. M. T.Efeito alelopático do extrato aquoso de folha e de fruto de leucena (*Leucaena leucocephala* Wit) sobre a germinação e crescimento de raiz da canafístula (*Peltophorum dubium* Spreng.). **Ciências Agrárias**, Londrina, v. 26, n. 2, p. 161-166, 2005.

SCHERER, L. E., BALDISSERA, I. T. & NESI, C. N.. Propriedades químicas de um latossolo vermelho sob plantio direto e adubação com esterco de suínos. **R. Bras. Ci. Solo,** v. 31, p.123-131, 2007.

SILVA, J.A.A.; DONADIO, L.C.; CARLOS, J.A.D. Adubação verde em cítrus. Jaboticabal: Funep, v. 37, p.233.239, 1999.

SIQUEIRA NETO, M..; FILHO, S. P.V.; PICCOLO, M C.; CERRI, C. E. P.; CERRI. C. C. Rotação de culturas no sistema plantio direto em Tibagi (PR). I - Sequestro de carbono no solo. **Rev. Bras. Ciênc. Solo,** v.33, n.4, Viçosa , 2009.

SOARES, G. L. G. Potencial alelopático do extrato aquoso de folhas de algumas leguminosas arbóreas brasileiras**. Floresta e Ambiente**, v. 9, n. 1, p.119-126, 2002.

SOUZA FILHO, A.P.S.e ALVES, S.M. Potencial alelopático de plantas de acapu (vouacapoua americana): efeitos sobre plantas daninhas de pastagens. **Planta Daninha**, Viçosa-MG, v.18, n.3, p.435-441, 2000.

VAZ DE MELO, A. Dinâmica populacional de plantas daninhas em cultivo de milho-verde nos sistemas orgânico e tradicional. **Planta Daninha**, Viçosa-MG, v. 25, n. 3, p. 521-527, 2007.

VEGA, J. M., MESSINGB, I.. The influence of land use and fallow period on the properties of two calcareous soils in the humid tropics of southern Mexico. **Catena.** v. 60, p. 279–292, 2005.

VESTENA, SI., FETT-NETO, A.G., DUARTE, R. C., FERREIRA ,A. G. Regulation of mimosine accumulation in Leucaena leucocephala seedlings. **Plant Science** v.161, p. 597–604, 2001.

VREELAND. JR e JAMES, M. The revival of colored cotton. **Scientific American**, V. 280, p- 112, 1999.

WESTON, L.A.Utilization of allelopathy for weed management in agroecosystems. **Agron. J.** v. 88, p. 860–866, 1996.

Interactions among leguminous trees, crops and weeds in a no-till alley cropping system

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Abstract Trees improve the soil quality and their rapid growth in the tropics make agroforestry systems potentially effective for establishing low-input agricultural systems in this region. This study assessed the effects of the biophysical interactions among leguminous trees, weeds, cotton and maize in an alley cropping system. The experiment comprised six treatments and four replicates in randomised blocks. This design resulted in the following treatments, Clitoria + Gliricidia (C+G); Acacia + Gliricidia (A+G); Leucaena + Clitoria (L+C); Leucaena + Acacia (L+A), Leucaena + Gliricidia (L+G) and Control (no residues). In January 2010, cotton and maize were sown among the legumes in sub-plots of 10 x 4m. The comparison of the results for cotton and maize confirmed that the effects of the trees on productivity can be very different for different crops. The residues did not produce variations in the chemical indicators that would account for the differences among the treatments with respect to the performance of the cash crops or for the weeds. The sensitivity of some crops to the allelopathic effects induced by the tree residues is evident mainly in root growth, in nutrient uptake and in the growth of the shoot. The results presented here support the view that the criteria for the choice of tree species for agroforestry systems must go well beyond the potential to enhance soil fertility to obtain the best results from agroforestry systems.

Keywords Allelopathy · Cotton · Leguminous residue · Maize

Introduction

The rapid growth of trees in the tropics makes agroforestry systems potentially effective for establishing low-input agricultural systems that are suitable for small holders. This approach has the advantage of bringing together crop cultivation and soil fertility regeneration in the same space and at the same time (Moura et al 2009a). Trees improve the soil quality by providing organic matter, reducing weed populations, assisting in nutrient recovery from the deeper soil layers, and adding nitrogen. However, trees have a major influence on crops owing to their perennial nature, large size and better adaptability. Trees also modify the biophysical environment to favour their own growth. In addition, a number of negative or antagonistic interactions, both competitive and allelopathic, may influence agroforestry systems. In view of this situation, the key to success in agroforestry is to minimise the negative interactions and maximise the positive interactions to obtain the best results (Thevathasan and Gordon 2004).

In the cohesive low-fertility soil of the humid tropics, no-till alley cropping can be an efficient system to maintain maize productivity. However, to maximise the positive interactions, it is necessary to ensure an adequate release rate of nutrients and to maintain soil cover, thus improving the soil rootability, during the entire crop cycle (Moura et al 2010). According to Aguiar et al. (2010), a good strategy is to use a combination of tree species that provide a combination of low-and high-quality residues. However, multispecies systems represent serious challenge for current agricultural research and, more specifically, for systemic agronomy because it is difficult to understand the effects of the different factors that interact within these systems (Malézieux et al. 2009). Therefore, although the mixture of residues offers some advantages, it may also increase the difficulty in understanding the ecological interactions between trees and crops in such intercropped systems. Such understanding is fundamental to the design of efficient systems having the potential for broader applicability. Furthermore, the occurrence of weeds is higher in this region, and a no-till system may be undesirable for the farmer because this type of system increases the aggressiveness of weedy species (Araújo et al. 2007).

Although several other authors have noted that alley cropping can meet the need for rain-fed upland farming with low external chemical inputs, most of these authors were concerned with the positive interactions between trees and staple foods (Kang 1997; Pandey et al. 2001; Moura et al. 2010). Conversely, tree-crop interactions have been considered as a source of damage. These considerations are almost always associated with the effect of trees on the growth of crops through competition for moisture, light and nutrients (Ong 1995; Imo and Timmer 2000). Less attention has been given to antagonistic interactions between trees, weeds and crops in diversified systems, including systems that produce fibre or oil.

Some controversial experimental results and the coexistence of allelopathy and resource competition in the natural environment make scientists sceptical about the possibility of distinguishing allelopathy from resource competition under field conditions (Bouchagier and Efthimiadis 2010; Albuquerque et al. 2011). Undoubtedly, the potential positive or negative allelopathic effects of tree residues on crops under field conditions still have not been properly addressed. Therefore, more information about the interactions among trees, crops and weeds is needed to move towards low-input systems, diversified and sustainable over the long term that will be adequate for smallholder agriculture in the humid tropics.

To contribute additional information about the correct use of trees in the sustainable management of tropical diversified agrosystems, this study assessed the effects of biophysical interactions among leguminous trees, weeds, cotton and maize in an alley cropping system.

Methods

Experimental area

The experiment was conducted at Maranhão State University, 2°30′ S, 44°18′ W. The region has a hot and semi-humid equatorial climate with a mean precipitation of 2,100 mm year^{-1} and two well-defined seasons: a rainy season that extends from January through June and a dry season with a marked water deficit from July through December. The soil was classified as Arenic Hapludult and contained 260 g kg^{-1} coarse sand, 560 g kg^{-1} fine sand, 80 g kg^{-1} silt, and 100 g kg^{-1} clay. The area was limed in January 2002 with a surface application of 1 Mg ha^{-1} hydrated calcium, corresponding to 279 and 78 kg ha^{-1} of Ca and Mg, respectively. The alley cropping system was initiated six months after liming. The results of the chemical analysis of the soil before and one year after the application of lime can be found in Moura et al. (2009b). Full details of the experimental design are given in Aguiar et al. (2010) and Moura et al. (2009b).

The alley cropping system experiment comprised six treatments and four replicates in randomised blocks. We tested four leguminous species. Two of these species, *Leucaena leucocephala* (leucaena) and *Gliricidia sepium* (gliricidia), have high-quality residues. The other two, *Clitoria fairchildiana* (clitoria) and *Acacia* *mangium* (acacia), have low-quality residues. It is noteworthy that of these legumes, only the clitoria is a native species. The trees were planted with 0.5 m spacing in 21 × 4 m parcels and in mixed rows so that each parcel received both types of residue. This design resulted in the following treatments, each consisting of a combination of two legumes: Clitoria + Gliricidia (C+G); Acacia + Gliricidia (A+G); Leucaena + Clitoria (L+C); Leucaena + Acacia (L+A), Leucaena + Gliricidia (L+G) and Control (no residues). Maize was sown every January between 2002 and 2009, with a 90 cm inter-row space and a 20 cm interplant space, and was treated with 250 kg ha^{-1} of a fertiliser whose composition was N-P-K 10-25-15+0.05% Zn.

In December 2009, the biomass resulting from the pruning of the legume trees was distributed homogeneously throughout all of the plots representing the same treatment. Table 1 shows the quantities of dry biomass produced by these treatments.

TABLE 1

In January 2010, cotton was sown among the legumes. The cultivar 7MH brown (*Gossypium hirsutum* L.) was sown in sub-plots of 10 x 4m using a 90 cm inter-row space and a 20 cm interplant space. The basic fertilisation applied to the cotton was 22 kg ha^{-1} urea, 180 kg ha^{-1} P_2O_5 and 70 kg ha^{-1} K_2O. A side dressing of 40 kg ha^{-1} urea was applied 30 days after emergence. In the same plots, maize (cultivar AG 7088) was sown with a 90 cm inter-row space and a 20 cm interplant space in sub-plots of 10 x 4m and was fertilised with 250 kg ha^{-1} of N-P-K 10-25-15+0.05% Zn. In addition, 30 kg ha^{-1} of N was applied in the form of urea when the fourth pair of leaves appeared.

Evaluation and statistical analysis

Three samples per plot were taken to a depth of 20 cm for soil chemical analysis. We analysed Ca, Mg, K, P and H + Al, and we measured the pH using $CaCl_2$ (IAC

2001). We also determined the cation exchange capacity (CEC) using the formula [SB + (H + Al)], where SB = Ca, Mg, K. We determined the base saturation using the formula (SB / CEC) × 100).

Weeds were collected from within a square 0.5 m on a side in the cotton area. The square was placed randomly at three points within the plot. The identification of plants was performed according to Kissmann and Groth (1992; 1995) and Kissmann (1997). After identification, the plants were counted and dried at 70°C to constant weight. The population dynamics of the weeds was evaluated by calculating the absolute and relative densities, richness, biomass, and species diversity. The species diversity was obtained from the Shannon-Wiener index (Pinto-Coelho 2000), given by = 1 pi Σsi ln pi, where s is the number of species, pi is the ratio of the density of species i to the total density of all species, and ln is the natural logarithm.

The cotton roots were sampled at the stage of the first appearance of the boll. An auger with a volume of 475.2 cm^3 was used. Samples were taken from each row of cotton. Three samples were taken from each plot at a depth of 0-20 cm. The samples were prepared by passing them through sieves. A 2 mm sieve was used on top, and a 1 mm sieve was used at the bottom, as specified in Bohm (1976).The soil was separated from the roots using water jets. The impurities were then separated from the roots. The roots were counted using the Newman line intersection method as modified by Tennant (1975). The roots obtained from each volume of soil were placed in ruled petri dishes. The rulings system in the humid tropics system in the humid tropics formed a grid of 0.5 x 0.5 cm. Each root that intersected a row of the grid was tallied using a manual counter. The cumulative total was converted into the root length density (RLD) using the formula RLD = (11/14 * Number of intersections (N) * Unit squared) / 475.2 (cm cm^{-3}).

Samples of cotton plants were collected at two stages of growth. Ten plants per plot were removed at the flowering stage and at the stage of physiological maturity of the whole plant. The samples were placed in paper bags, transferred to the laboratory, and dried using forced air at 65°C. After drying, the samples of whole plants were weighed on an analytical balance to estimate the dry mass accumulated in the shoot. The materials were then ground. The total N, P, K, Ca and Mg concentrations in the cotton plants were determined following H_2SO_4-H_2O_2 digestion according to the standard method described by Tedesco et al. (1995).

In cotton, the yield parameters evaluated were the number of bolls, the weight of the seeds, the percentage of fibre and the weight of the bolls. The yield parameters for maize were evaluated at the final harvest. The weight of the ears, the number of ears, the 100 grain weight and the weight of grains were determined.

The data were statistically analysed using STATISTICA software. The analysis of variance was applied to the results of the chemical analyses; to the data on root density, dry weight, species diversity, plant density and biomass; and to the yield parameters of cotton and maize. The comparison of means was performed using the Tukey test at a significance level of 5%. The Sigma Plot 11.0 program (Systat Cabinet Software Inc.) was used to produce the graphics.

Results

The application of the residues affected only the levels of Ca and Mg of the soil. These effects were reflected in small increases in the Sum of Bases and Percent Base Saturation in the cover soil compared with the control (Table 2). However, this modification was not sufficiently large to affect the critical levels of the chemical indicators (Ribeiro et al. 1999).

TABLE 2

The residues did not produce any differences in the density and richness of the weed species (Table 3). In all, 16 species were recorded in the total area examined in the experiment. In addition, the diversity index values of approximately 0.5 found in all treatments indicate that the diversity and abundance were not affected by the different mixtures of residues used. However, the amount of weed biomass in (C+G) was more than twice that found in (L+A). The weed biomass did not differ significantly among the other treatments or between these treatments and the control.

TABLE 3

The 10 weeds observed most frequently in the experiment only appeared together in the treatments with clitoria (Table 4). Of these species, *Cleome affinis* DC., *Spigelia anthelmia* L. and *Croton lobatus* L. did not appear in (L+G), and *Mollugo verticillata* L. and *Synedrellopsis grisebachii* Hieron did not appear in (L+A). Moreover, it is noteworthy that one of the most important weeds in tropical agriculture, *Commelina benghalensis* L., did not appear in (A+G) and appeared at a much lower density in (L+A), although it was the second most frequent weed in the treatments with clitoria.

TABLE 4

For cotton, the greatest root length density (RLD) was found in the combination of clitoria and gliricidia (C+G). In the combinations of gliricidia with acacia (A+G) and leucaena (L+G), the root growth was lower. The treatments (L+C) and (L+A) showed intermediate results. The accumulation of dry matter (DMA) was lower in the mixed residues with acacia, (L+A) and (A+G), than in the other combinations of residues. No differences in DMA were found among these other combinations, which were not different between them. The difference between the (L+A) and (C+G) treatments was almost 100%. The lower RLD of (L+G) did not prevent this treatment from exhibiting a DMA value equal to that of (C+G) and much higher than that of (L+A), even though (L+A) and (L+G) had equal values of RLD. A higher DMA:RLD ratio was observed for the treatments that included leucaena except that with acacia (Fig. 1).

FIGURE 1

In cotton, the levels of the main nutrients did not differ among the residue treatments at the flowering stage (Table 5). In contrast, remarkable differences were observed in the N, K and Ca uptake at maturity. (C+G) showed over 50% more nitrogen than (A+G) and 33% more than (L+A). The differences in potassium uptake between the same treatments were 75% and 40%, respectively. The calcium uptake also varied significantly between these treatments, but the differences were smaller.

TABLE 5

The interactions of corn and cotton with the mixtures of residues differed markedly. The greatest difference was found between (L+A) and (C+G) (Table 6). The cotton was negatively affected by leucaena if leucaena was not combined with clitoria, but the damage was very high if leucaena was combined with acacia. The yield of fibre was almost three times smaller in (L+A) than in (C+G). Clitoria dampened the negative effect of leucaena, but gliricidia did not do so. Thus, the cotton yields in (C + L) and (G + C) were much higher than that in (L + A). All of the parameters of productivity of the cotton evaluated were negatively affected by the combination of leucaena plus acacia.

Conversely, for maize, the (L+A) treatment was superior, with a yield 26% higher than that for (C+G). (C+L) was also superior to all of the other treatments. The yield parameters of the maize did not differ significantly among the treatments.

TABLE 6

Discussion

Even though large amounts of residues and fertilisers were applied during the seven years following the establishment of the plantation, the analyses of the soil used in the experiment showed that the levels of all of the chemical indicators analysed were less than those established for fertile tropical soil (Ribeiro et al. 1999). In addition, the application of different residues did not produce significant variations in the chemical indicators that would account for the differences among the treatments observed with respect to the performance of the cash crops or for the weeds. The design and management of the experiment aimed to avoid above-ground competition between the trees and the crops. Therefore, to explain the results of this experiment, the non-resource interactions among the components of the alley cropping system must be considered.

The residues affected the growth of weedy species more than the occurrence of these species in the community. The effect of residues was primarily observed in the plots with acacia and leucaena. This finding may be important in light of the observation that the weeds were much more aggressive in (C+G) than in (L+A) treatment. According to Maclean et al. (2003), alley cropping offers three ways to reduce the competition between crops and weeds. Green manuring can improve the physico-chemical properties of the soil and alter the species composition of the weed community, shade can reduce the growth of weed species that are sensitive to shading, and mulching can prevent weed germination. In this experiment, only the mulching effect could potentially serve to explain differences among the treatments. Furthermore, the physical weeds suppression resulting from mulching was not important. The control did not differ from some treatments (A+G and L+G) in which the plots were totally covered. Hence, the variation in the impact of the mulching on the density and growth of weeds may be associated more with the biological effects of the allelopathic products released by the decomposition of the residues (Putnam et al. 1983). In this context, the opposite effects on weed occurrence and biomass exhibited by clitoria, a native legume, and by acacia and leucaena, both exotic species, show that the tree species chosen for the alley cropping system may modify the interactions between the components of the system and increase or decrease the competitiveness of the weeds. The high weed biomass for the (C+G) treatment indicates that the weeds in those plots benefitted from nutrient release but were not affected by allelopathic substances.

The suppressive effect of leucaena on weeds is well known (John and Narval 2003; Yeung et al. 2002; Williams and Hoagland 2007) and is attributed to at the release of mimosine, which is a non-protein amino acid that occurs in its leaves and seeds. In acacia, Luz et al. (2010) have reported the presence of the substance lupenone, which is a triterpenoid that has allelopathic effects on the germination of seeds of several weed species. Conversely, it is important to note the antagonistic effect of the residues of clitoria on the suppression of weeds by leucaena residues. Aguiar et al. (2010) have reported that the composition of the weed community changed after four years in an alley cropping system with clitoria. These changes resulted mainly from the increase of such species as *Commelina benghalensis* L. In both cases, the weeds took advantage of improvements in soil fertility produced by the residues of native plants in the absence of overt antagonism. These antagonistic effects are more commonly caused by exotic plants, as described by Hierro and Callaway (2003) and Bais et al. (2003).

The root growth of the cotton in this experiment was shown to depend on the physical improvement of the rootability of the soil produced by the mulch and the antagonistic effect of the residues on the growth of the roots. This finding is consistent with the idea that the lower root length density (RLD) in the plots without residues resulted from the hardening of the soil. Such soil hardening affects root growth after only four days without rain in uncovered plots (Becher et al. 1997 and Ley et al. 1995). However, the RLD of the cotton was higher in the (C+G) treatment than in the (A+G), which someone could not wait, from the data of Moura et al. (2009b). These authors found major improvements in the soil rootability in plots with acacia in the same experiment three years ago. Moreover, even under the same conditions, Oliveira (2011) found that the RLD of maize was higher in (A+G) plots than in (C+G) plots. These results confirm that the improvement in the soil properties caused by the residues from trees cannot be generalised to all cash crops without considering the antagonistic effects that may occur. Such antagonistic effects probably result from the release of allelopathic substances during the decomposition of the residues.

The treatments involving leucaena, acacia and clitoria in combination with gliricidia clearly indicated that both the acacia and leucaena were detrimental to the growth of cotton roots. According to Luz et al. (2010), in several species, the effects of lupenone, which is a substance produced by *Acacia mangium*, may result in decreases in radicle growth of as much as 40%. Root growth inhibition caused by the mimosine present in leucaena has been associated with reductions in the phenylalanine and peroxidase activities and the lignin content, according to Andrade et al. (2008). The inhibitory effect of leucaena on root growth, combined with the increased release of nutrients, may have been the reason that the DMA: RLD ratio tended to be higher in the (L + G) and (C+L) treatments.

The uptake of available nutrients by crops is closely related to the rootability of the soil. The uptake of N, K, and Ca was therefore affected by the growth of the roots, but the (L+C) and (L+G) treatments also benefitted from the higher nutrient liberation rate of the leucaena residues. According to the results obtained by Moura et al. (2010) in the same area, the (L+A) and (L+C) treatments produced better conditions and a higher uptake of N and K by the maize by providing a good balance of low- and high-quality residues. This balance permitted an increase in the release time of N and K. Furthermore, it allowed the soil to remain covered during the entire crop cycle and thus improved the rootability of the soil.

In the cotton plants investigated in this experiment, other factors, beyond the root growth and nutrient availability, must have contributed to the large differences in the N, K and Ca contents between the (A+G) and (L+G) treatments. The RLDs of the two treatments were similar, and the difference between the two treatments in the amount of nutrients released was not important (Oliveira 2011). According to Zhang et al. (2010), phenolic acids are present at very high concentrations in *Acacia mangium*, which can alter the rate at which ions are absorbed by plants (Rice 1984). Reductions in both macro-and micronutrients are generally encountered in the presence of phenolic acids. According to Glass (1974), one mechanism by which plant growth is inhibited by this class of allelochemicals may be an alteration in the membrane permeability. However, Brum and Gerig (2005) have suggested that some species can modify the concentration of active phenolic acids surrounding their roots and can influence the magnitude of the primary and secondary effects of phenolic acids. This suggestion indicates that phenolic acids may have different effects on maize and cotton roots. Cotton is also more sensitive to K fertiliser than corn and soybean, probably because the root system of cotton is less dense at depths of <0.3 m in the soil (Zhang et al. 2009). K absorption is therefore highly dependent on root activity. Vigorous growth of root systems is required to intercept and absorb available K (Sawyer and Mallarino 2002).

The comparison of the results for cotton and maize confirmed that the effects of the trees on productivity can be very different for different crops. Unfortunately, this effect can be independent of the capacity of the residues to release nutrients and of the levels of the indicators of enhanced soil quality. In this study, the maize was able to benefit from the improvements in nutrient release and soil rootability furnished by the beneficial combination of low- and high-quality residues in the (L+A) and (L+C) treatments. In contrast, the cotton did best in the (C+G) treatment, probably because the level of antagonistic substances was lower. This characteristic also promoted weed growth.

Furthermore, the effects of the (L+A) treatment on the growth and productivity of the cotton must have reflected the influence of antagonistic substances on the plant's metabolism because productivity was much lower, despite the higher potential for nutrient release and enhanced soil rootability. According to Batish et al. (2007), crops growth may suffer the effects of the residues of allelopathic plants. These effects include decreases in the amounts of total chlorophyll and the contents of water-soluble proteins and the total carbohydrates and area consequence of the degradation or reduced synthesis of these compounds.

Conclusions

The results presented here support the view that the criteria for the choice of tree species for agroforestry systems must go well beyond the demonstrated potential to enhance soil fertility and prevent resource competition. Therefore, information on the complex and specific interactions linking trees, cash crops and weeds is needed to take advantage of the relationships between trees and crops and to obtain the best results from agroforestry systems. Under field conditions, the sensitivity of some crops to the allelopathic effects induced by the tree residues is evident mainly in root growth, in nutrient uptake and in the growth of the shoot. Thus, the combined use of two allelopathic species, such as leucaena and acacia, may decrease the yield of the sensitive cash crops and cancel the positive effects of the trees on nutrient availability and soil rootability. Therefore, the inclusion of a non-allelopathic (perhaps a native) species having additional desirable characteristics in the mixture of residues could be a good potential strategy. This approach would help to mitigate the negative effect of species such as leucaena on the cash crops and would furnish a high potential for the release of nutrients throughout the crop cycle. The biological impact of residues on the occurrence of weeds is very specific, for this reason its successfull use depend on sensitivity of the principal weeds and of tolerance of the crop to allelopatic effect.

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References

Albuquerque MB, Santos RC, Lima LM, Melo Filho PA, Nogueira RJMC, Câmara CAG, Ramos AR (2011) Allelopathy, an alternative tool to improve cropping systems. A review. Agron Sustain Dev 31:379-395

Aguiar ACF, Bicudo SJ, Costa Sobrinho JRS, Martins ALS, Coelho KP, Moura EG (2010) Nutrient recycling and physical indicators of an alley cropping system in a sandy loam soil in the Pre-Amazon region of Brazil. Nutr Cycl Agroecosys 86:189-198

Andrade AB, Ferrarese MLL, Teixeira AF, Ferrarese-Filho O (2008) Mimosine-inhibited soybean (*Glycine max*) root growth, lignification and related enzymes. Allelopathy J 21:145-154

Araujo JC, Moura EG, Aguiar ACF, Mendonça V (2007) Supressão de plantas daninhas por leguminosas anuais em sistema agroecológico na Pré-Amazônia. Planta Daninha 25:267–275

Bais HP, Vepachedu R, Gilroy S, Callaway RM, Vivanco JM (2003) Allelopathy and exotic plant invasion: from molecules and genes to species interactions. Science 301:1377-1380

Batist DR, Lavanya K, Singh HP, Kohli RK (2007) Phenolic allelochemicals released by *Chenopodium murale* affect the growth, nodulation and macromolecule content in chickpea and pea. Plant Growth Regul 51:119-128

Becher HH, Breuer J, Klingler B (1997) An index value for characterizing hardsetting soils by fall-cone penetration. Soil Tech 10:47–56.

Bohm W (1976) Methods of studying root systems. New York, Springer-Verlag. 192p.

Bouchagier P, Efthimiadis P (2010) Allelopathic susceptibility of cotton to bermudagrass. J Agron 9:23-28

Brum U, Gerig TM (2005) Relationships between phenolic acid concentrations, transpiration, water utilization, leaf area expansion, and uptake of phenolic acids: nutrient culture studies. J Chem Ecol 31:1907-1932

Glass ADM (1974) Influence of phenolic acids on ion uptake. IV. Depolarization of membrane potentials. Plant Physiol 54:855-858

Imo M, Timmer VR (2000) Vector competition analysis of a *Leucaena*-maize alley cropping system in western Kenya. For Ecol Manag 126:255-268

Hierro JL, Callaway RM (2003) Allelopathy and exotic plant invasion. Plant Soil 256:29-39

Kang BT (1997) Alley cropping—soil productivity and nutrient recycling. For Ecol Manag 91:75–82

Kissmann KG, Groth D (1992) Plantas infestantes e nocivas. São Paulo: Basf. Tomo II. 798 p.

Kissmann KG, Groth D (1995) Plantas infestantes e nocivas. São Paulo: Basf. Tomo III. 683 p.

Kissmann KG (1997) Plantas infestantes e nocivas. 2.ed. São Paulo: Basf. Tomo I. 824 p.

John J, Narwal SS (2003) Allelopathy plants. Leucaena leucocephala (Lam.) de Wit. Allelopathy J 12:13-36

Ley GJ, Mullins CE, Lal R (1995) The potential restriction to root growth in structurally weak tropical soils. Soil Till Res 33:133–142

Luz SM, Souza Filho APS, Guilohn GMSP, Vilhena KSS (2010) Atividade alelopática de substâncias químicas isoladas da *Acacia mangium* e suas variações em função do pH. Planta Daninha 28:479-487

Maclean RH, Litsinger JA, Moody K, Watson AK, Libetario EM (2003) Impact of *Gliricidia spectabilis* hedgerows on weeds and insect pests of upland rice. Agric Ecos Environ 94:275–288

Malézieux E, Crozat Y, Dupraz C, Laurans M, Makowski D, Ozier-Lafontaine H, Rapidel B, de Tourdonnet S, Valantin-Morison M (2009) Mixing plant species in cropping systems: concepts, tools and models. A review. Agron Sustain Dev 29:43-62

Moura EG, Coelho KP, Freitas IC, Aguiar ACF (2009a) Chemical and physical fertility indicators of a weakly structured tropical soil after liming and mulching. Sci Agric 66:800–805

Moura EG, Moura NG, Marques ES, Pinheiro KM, Costa Sobrinho JRS, Aguiar ACF (2009b) Evaluating chemical and physical quality indicators for a structurally fragile tropical soil. Soil Use Manage 25:368–375

Moura EG, Serpa SS, Santos JGD, Costa Sobrinho JRS, Aguiar ACF (2010) Nutrient use efficiency in alley cropping systems in the Amazonian periphery. Plant Soil 335:363-371

Oliveira AKC (2011) Atributos físicos do solo e crescimento de raízes do milho no sistema de plantio direto sobre palha de leguminosas. (M.Sc. Dissertation), Universidade Estadual do Maranhão, São Luís, 30 p.

Ong CK (1995) The 'dark side' of intercropping: manipulation of soil resources. In: Sinoquet H, Cruz P (Eds.), Proceedings of the International Conference on Ecophysiology of Intercropping. INRA, Paris, France, pp. 45-66.

Pandey CB, Sharma DK, Singh AK (2001) *Leucaena* – Linseed competition in an alley-cropping system in central India. Tropical Ecology 42:187-198

Pinto-Coelho, RM (2000) Fundamentos em ecologia. Porto Alegre: Artmed. 252 p.

Putnam AR, Defrank J, Barnes JP (1983) Exploitation of Allelopathy for weed control in annual and perennial cropping systems. J Chem Ecol 9:1001-1010

Ribeiro AC, Guimarães PTG, Alvarez VHV (1999) Recomendações para o uso de corretivos e fertilizantes em Minas Gerais—5a Aproximação. UFV, Viçosa.

Rice EL (1984) Allelopathy. Academic Press, Orlando.

Sawyer JE, Mallarino AP (2002) Corn leaf potassium deficiency symptoms. In: The Integrated Crop Management Newsletter. IC-488(15). Iowa State Univ. Extension

Tedesco MJ, Gianello C, Bissani CA, Bohnen H, Volkweiss SJ (1995) Análise de solos, plantas e outros materiais. UFRGS, Porto Alegre.

Tennant DA (1975) Test of a modifield line intersect method of estimating root lenght. J Ecol 63:995-1001

Thevathasan NV, Gordon AM (2004) Ecology of tree intercropping systems in the North temperate region: experiences from southern Ontario, Canada. Agrofor Syst 61:257-268

Williams RD, Hoagland RE (2007) Phytotoxicity of mimosine and albizziine on seed germination and seedling growth of crops and weeds. Allelopathy J 19:423-430

Yeung PKK, Wong FTW, Wong JTY (2002). Mimosine, the allelochemical from the leguminous tree *Leucaena leucocephala*, selectively enhances cell proliferation in Dinoflagellates. Appl Environ Microb 68:5160-5163

Zhang L, Chen J, Wang Y, Wu Y, Xu M (2010) Phenolic extracts from *Acacia mangium* Bark and their antioxidant activities. Molecules 15:3567-3577

Zhang ZL, Wang QL, Li ZH, Duan LS, Tian XL (2009) Effects of potassium deficiency on root growth of cotton seedlings and its physiological mechanisms. Acta Agron Sin 35:718-723

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Table 1 Quantities of dry biomass produced and applied by treatments in 2010.

	C + G	L + G	A + G	C + L	L + A
Dry biomass (Mg ha^{-1})	24	16	30	22	39

C+G= Clitoria+Gliricidia; L+G=Leucaena + Gliricidia; A+G=Acacia + Gliricidia;

C+L=Clitoria + Leucaena; L+A=Leucaena + Acacia

Table 2 Chemical characteristics of soil after the experiment in 2010

	C+G	L+G	A+G	C+L	L+A	Control
Ca ($\mathrm{cmol_c\ kg^{-1}}$)	7.2 a	7.3 a	7.4 a	8.1 a	8.6 a	4.1 b
Mg ($\mathrm{cmol_c\ kg^{-1}}$)	1.6 a	2.0 a	1.8 a	2.2 a	2.4 a	1.0 b
K ($\mathrm{cmol_c\ kg^{-1}}$)	0.4 a	0.5 a	0.5 a	0.5 a	0.3 a	0.7 a
P ($\mathrm{mg\ kg^{-1}}$)	13.6 a	13.2 a	20.6 a	14.0 a	8.1 a	15.7 a
Sum of Bases ($\mathrm{cmol_c\ dm^{-3}}$)	9.2 a	9.8 a	9.6 a	10.8 a	11.3 a	5.8 b
Potential acidity ($\mathrm{cmol_c\ dm^{-3}}$)	35.5 a	38.1 a	32.7 a	36.2 a	39.0 a	38.2 a
CEC ($\mathrm{cmol_c\ kg^{-1}}$)	44.7 a	47.9 a	38.5 a	47.0 a	50.3 a	44.0 a
pH ($CaCl_2$)	4.1 a	4.1 a	3.8 a	4.1 a	4.0 a	4.0 a
Base saturation percentage %	20.1 a	19.3 a	16.6 ab	22.5 a	21.8 a	13.1 b

Different letters in the same row indicate difference at the 5% level by Tukey test.

C+G= Clitoria+Gliricidia; L+G=Leucaena + Gliricidia; A+G=Acacia + Gliricidia; C+L=Clitoria + Leucaena; L+A=Leucaena + Acacia

Table 3 Effects of coverage on density, species richness, Shannon-Winer index and biomass weed

	C+G	L+G	A+G	C+L	L+A	Control
Density, plants m^2	61.0 a	52.0 a	60.0 a	51.0 a	41.0 a	63.0 a
Richness, species m^2	22.0 a	18.0 a	19.0 a	19.0 a	16.0 a	17.0 a
Shannon-Winer Index	0.6 a	0.5 a	0.5 a	0.6 a	0.5 a	0.5 a
Biomass, g m^2	110.0 a	67.2 ab	68.9 ab	62.3 ab	44.8 b	88.6 ab

Different letters in the same row indicate difference at the 5% level by Tukey test.

C+G= Clitoria+Gliricidia; L+G=Leucaena + Gliricidia; A+G=Acacia + Gliricidia;

C+L=Clitoria + Leucaena; L+A=Leucaena + Acacia

Table 4 Relative (RD) and absolute (AD) densities of weeds.

Species	Treatments											
	C+G		L+G		A+G		C+L		L+A		Control	
	RD	AD	RD	AD	RD	AD	RD	AD	RD	AD	RD	AD
C. punctatum Cass	42.6	104	45.5	100	65.0	156	31.4	64	56.1	92	49.2	124
C. benghalensis L.	18.0	44	27.3	60	-	-	21.6	44	4.9	8	11.1	28
M. verticilata L.	4.9	12	7.3	16	5.0	12	11.8	24	-	-	14.3	36
A. tenella Colla	4.9	12	3.6	8	8.3	20	11.8	24	7.3	12	3.2	8
C. affinis DC.	4.9	12	-	-	5.0	12	5.9	12	14.6	24	3.2	8
S.anthelmia L.	8.2	20	-	-	3.3	8	3.9	8	4.9	8	1.6	4
C. lobatus L.	3.3	8	-	-	3.3	8	2.0	4	2.4	4	3.2	8
S. grisebachii Hieron	1.6	4	7.3	16	3.3	8	2.0	4	-	-	-	-
P. phaseoloides	1.6	4	5.5	12	1.7	4	3.9	8	2.4	4	1.6	4
Cyperus esculentus L.	1.6	4	1.8	4	1.7	4	3.9	8	2.4	4	-	-

C+G= Clitoria+Gliricidia; L+G=Leucaena + Gliricidia; A+G=Acacia + Gliricidia; C+L=Clitoria + Leucaena; L+A=Leucaena + Acacia

Table 5 Nutrient content at flowering and maturity of the cotton plant.

	Nutrient contents at flowering					
	C+G	L+G	A+G	C+L	L+A	Control
N g kg^{-1}	39.0 a	36.8 a	34.5 ab	38.1 a	34.6 ab	25.6 b
P g kg^{-1}	2.4 a	2.4 a	2.2 a	2.1 a	2.2 a	1.8 a
K g kg^{-1}	10.3 a	9.3 a	8.9 a	8.8 a	9.6 a	7.8 a
Ca g kg^{-1}	5.88 a	5.63 a	5.43 a	5.89 a	5.21 a	5.36 a
Mg g kg^{-1}	1.69 a	1.66 a	1.56 a	1.82 a	1.67 a	1.26 a
	Nutrient contents at maturity					
	C+G	L+G	A+G	C+L	L+A	Control
N g kg^{-1}	69 a	63ab	45c	64 ab	54 bc	14 d
P g kg^{-1}	6 a	7 a	4 ab	7 a	5 ab	2 c
K g kg^{-1}	14 a	12 ab	08 c	11 b	10 b	2 d
Ca g kg^{-1}	13.90 a	13.99 a	10.32 c	13.62 a	11.59 b	3.50 d
Mg g kg^{-1}	4.93 a	5.30 a	3.32 a	4.49 a	3.41 a	0.77 b

Different letters in the same row indicate difference at the 5% level by Tukey test.

C+G= Clitoria+Gliricidia; L+G=Leucaena + Gliricidia; A+G=Acacia + Gliricidia; C+L=Clitoria + Leucaena; L+A=Leucaena + Acacia

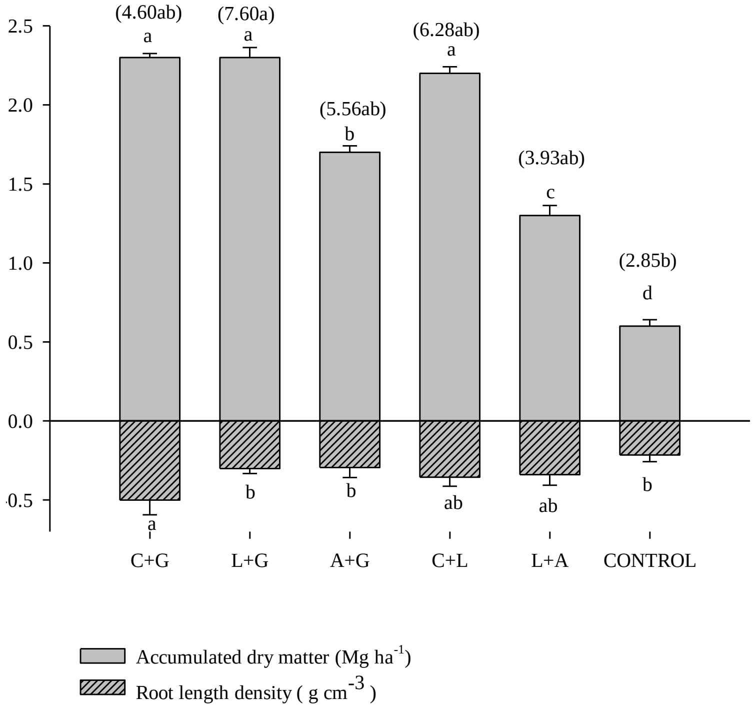

Figure 1. Accumulated dry weight of cotton, root length density (RLD) and ratio dry matter/RLD in brackets.

ANEXO

EUROPEAN JOURNAL OF AGRONOMY
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The European Journal of Agronomy, the official journal of the European Society for Agronomy, publishes original research papers reporting experimental and theoretical contributions to crop science in the following fields:

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State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

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Results should be clear and concise.

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This should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section should be avoided. Avoid extensive citations and discussion of published literature.

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The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a Discussion or Results and Discussion section.

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Abstract

A concise and factual abstract is required. The abstract should state briefly the purpose of the research, the principal results and major conclusions. An abstract is often presented separately from the article, so it must be able to stand alone. For this reason, References should be avoided, but if essential, then cite the author(s) and year(s). Also, non-standard or uncommon abbreviations should be avoided, but if essential they must be defined at their first mention in the abstract itself.

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Reference to a chapter in an edited book:
Mettam, G.R., Adams, L.B., 2009. How to prepare an electronic version of your article, in: Jones, B.S., Smith , R.Z. (Eds.), Introduction to the Electronic Age. E-Publishing Inc., New York, pp. 281–304.

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