UNIVERSIDADE ESTADUAL DO MARANHÃO

CENTRO DE CIÊNCIAS AGRÁRIAS

PROGRAMA DE PÓS-GRADUAÇÃO EM AGROECOLOGIA

CURSO DE MESTRADO EM AGROECOLOGIA

VIRLEY GARDENY LIMA SENA

MELHORIA DOS INDICADORES FÍSICOS DE UM ARGISSOLO COESO POR MEIO DA APLICAÇÃO DE GESSO E BIOMASSA DE LEGUMINOSAS ARBÓREAS

São Luís

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Engenheira Agrônoma

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Dissertação apresentada ao Programa de Pós-Graduação em Agroecologia da Universidade Estadual do Maranhão, como parte das exigências para a obtenção do título de Mestre em Agroecologia.

Orientador: Prof. Dr. Emanoel Gomes de Moura

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DEDICO

Aos meus queridos pais, Raimundo Sena e Ana Maria, aos meus irmãos, Glécia e Gleydson, amores da minha vida por toda a eternidade.

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"Seja como uma árvore plantada à beira de águas correntes: que dá fruto no tempo certo e suas folhas não murcham, ou tal qual uma semente que caiu em terra boa, que cresce e produz muitos frutos."

Salmos 1,3
Mateus 13,23

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ENHANCEMENT OF THE ROOTABILITY OF A STRUCTURALLY FRAGILE TROPICAL SOIL USING GYPSUM AND LEGUMINOUS RESIDUES

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CAPÍTULO I

1 INTRODUÇÃO GERAL

O trópico úmido apresenta particularidades edafoclimáticas que constituem um grande obstáculo para implementação de sistemas agrícolas sustentáveis. A região apresenta altos índices pluviométricos e altas temperaturas, e os solos são em grande parte de baixa fertilidade natural, em torno de 60% derivados de rochas sedimentares clásticas (AGUIAR et al., 2010).

Práticas agrícolas, que são recomendadas para o cerrado brasileiro - como saturação do solo com fertilizantes solúveis e aração e gradagem -, não garantem a sustentabilidade dos agroecossistemas nessa região por não se adequarem às características edafoclimáticas locais. Logo, pode se enfatizar que a substituição de sistemas simples (corte e queima) por outros mais complexos, como plantio direto, não serão bem sucedidos sem um suporte público eficiente à agricultura familiar. O suporte deve incluir vetores tecnológicos básicos, tais como, corretivos, fertilizantes fosfatados e pequenos equipamentos agrícolas, seguido de um programa de assistência técnica para desenvolver os territórios rurais (MOURA et al., 2009).

Mediante a falta de suporte aos agricultores familiares, e também devido à falta de conhecimento de outras tecnologias, é predominante na região a agricultura de corte e queima, cujos objetivos são a limpeza da área a ser cultivada e o uso das cinzas como fertilizante, sustentadas durante muito tempo pela abundância de áreas disponíveis e pela baixa densidade demográfica (MOURA et al., 2008; AGUIAR et al., 2009).

Com o crescimento populacional, tem aumentado a demanda por terras cultiváveis, o que tornou progressivamente mais curto o tempo de pousio das áreas estabelecidas entre as queimas sucessivas (MOURA et al., 2008; MOURA et al., 2013). A adoção de um novo modelo agrícola, que contemple o uso de tecnologias que permitam a maximização da produção de alimentos na mesma área, pode reduzir a necessidade de *inputs* externos, o uso dos recursos naturais e valorizar os serviços ecossistêmicos.

A intensificação ecológica da agricultura (IEA), foi estabelecida com o intuito de produzir maior quantidade de alimentos por unidade de recursos e reduzir o impacto da produção de alimentos no meio ambiente, se justifica pela carência de terras aptas para expandir a agricultura e pela necessidade de redução de fontes não renováveis. Pretende ainda manter a fertilidade e biodiversidade dos solos, minimizar efeitos da erosão e aumentar a eficiência do uso de nutrientes (NELSON et al., 2010; HOCHMAN et al., 2011, GEHRING et al., 2013).

No trópico úmido, a maioria dos solos apresenta alta propensão à coesão e, consequentemente, alta resistência à penetração, o que dificulta a enraizabilidade das plantas e diminui a eficiência do uso de nutrientes (MOURA et al., 2009 a ; MOURA et al., 2010). Para aumentar a fertilidade e diminuir a coesão do solo nessa região, o plantio direto e a cobertura morta são mais eficientes que outras práticas comuns - como aração e gradagem – devido à contribuirem para formação de liteira que favorece o crescimento das raízes, pois, em solos de estrutura frágil, a proteção da superfície pode retardar o processo de redução da porosidade pelo colapso ou condensação da matriz do solo. Alguns desses solos são sujeitos à chuva intensa e, devido ao impacto, a chuva pode causar sua recompactação (BUSSCHER et al., 2002; ADEKALU et al., 2006; MOURA et al., 2008).

Além do plantio direto e da cobertura morta, a aplicação de gesso pode aumentar a atividade da raiz no subsolo, a estabilidade dos agregados e reduzir a resistência à penetração, o que proporciona um ambiente favorável ao crescimento radicular, ao aumento da eficiência da absorção de nutrientes e ao beneficio no crescimento e produtividade das culturas (RADCLIFFE et al., 1986; CAIRES et al., 2011). Estes processos possíbilitam que haja um uso mais eficiente dos nutrientes, entendido aqui como a capacidade das plantas de interesse agrícola em recuperar elementos minerais do solo (eficiência de recuperação) e utilizá-los posteriormente na produção agronômica (eficiência fisiológica) de modo mais rentável (MI et al., 2007)

O aprimoramento de técnicas de manejo capazes de balancear a necessidade do solo e das culturas, considerando a otimização da produção, a eficiência no uso dos recursos e garantia da produtividade, por um longo período em uma mesma área, poderá promover um avanço no modelo da agricultura maranhense. Portanto, esse estudo visa avaliar o efeito da utilização do gesso associado à cobertura com biomassa de leguminosas arbóreas e adubos minerais sobre a eficiência de utilização do fósforo e os indicadores físicos do solo em diferentes profundidades, ambos na cultura do milho.

2 REFERENCIAL TEÓRICO

2.1 Região Centro Norte do Maranhão

A região do centro norte maranhense está localizada na periferia da Amazônia e em função desta posição geográfica possui atributos bem diferenciados no que tange a solo e clima, com alta incidência de chuvas e temperaturas elevadas. Deste modo, as tecnologias a serem implementadas na agricultura deste local devem levar em conta essas especificidades, pois estudos experimentais desenvolvidos por Ferraz Jr (2004), Aguiar (2006) e Moura et al (2008) relatam que as práticas agrícolas usadas em outras partes do Brasil com êxito, para o centro norte do Maranhão, são ineficientes e insustentáveis.

A produção de alimentos básicos na região é, em sua maioria, proveniente da agricultura familiar, que em grande parte, devido à falta de políticas públicas que dê suporte aos agricultores familiares e a falta de conhecimentos sobre novas tecnologias agrícolas, acabam fazendo o uso de um sistema de plantio itinerante, denominado “roça no toco”. Esse sistema faz o uso predatório da vegetação natural para aproveitar as cinzas como fertilizante e permite a rápida limpeza da área com baixo custo, que é algo vantajoso para o agricultor. Esses benefícios, que foram significativos nos tempos de vegetação abundante e em regiões de baixa densidade demográfica, hoje se transformaram em fatores que dificultam a introdução de outros modelos agrícolas na região (FERRAZ JR, 2004; AGUIAR, 2006).

Segundo (MOURA et al., 2009 b), o uso predatório da vegetação natural como forma de garantir a subsistência das famílias rurais, constitui uma das fontes de pressão sobre os recursos naturais e estabelece-se, assim, um círculo vicioso em que as carências aumentam a pressão sobre os recursos e a degradação crescente dos recursos aumenta as carências. Assim sendo, aqueles que se dedicam à agricultura familiar no Maranhão não possuem uma produção que garanta sua segurança alimentar e nem a continuidade dessas famílias no meio rural.

Um dos grandes desafios nesta região é encontrar alternativas tecnológicas para a sustentabilidade dos agrossistemas em solos derivados de rochas sedimentares, submetidos a um alto grau de intemperização. Esses solos, de estrutura frágil, não suportam o uso intensivo exigido pela agricultura da forma como é praticada em outras regiões, por serem solos franco-arenosos com altas percentagens de areia fina, teores de silte entre 15 e 20%, argila entre 10 e

15%, e serem solos altamente intemperizados, apresentam baixa capacidade de retenção de cátions e pouca disponibilidade dos principais nutrientes vegetais (MOURA et al., 2008). Além disso, ciclos repetitivos de umedecimento e secagem, aliados aos baixos teores de carbono e de ferro livre, aumentam a coesão da superfície do solo pela atuação das partículas de silte e areia fina (MOURA et al., 2009 a,b).

No trópico úmido maranhense, o uso do fogo ainda é visto como uma das principais alternativas para implantação de cultivos agrícolas. Portanto, aumentar a produção agrícola via aumento de produtividade pelo uso racional de insumos é primordial para evitar a necessidade de abertura de novas áreas. O maior desafio para sustentabilidade da agricultura nessa região é identificar, reduzir o uso ineficiente dos nutrientes e simultaneamente se intensificar a produção, manter a fertilidade do solo, a biodiversidade e reduzir os impactos ambientais da agricultura (AGUIAR et al., 2014).

Tendo em vista tais aspectos, mais a crescente preocupação global com o meio ambiente, a implementação de um modelo agrícola que concilie o cultivo de culturas de interesse econômico com a sustentabilidade dos agrossistemas deve ser enfaticamente considerada. Tudo no intuito de atender a demanda de alimentos, aumentar a produtividade em áreas já cultivadas e fazer uso de tecnologias que não promovam a degradação de áreas agricultáveis, possibilitando um avanço no modelo de produção agrícola maranhense.

2.2 Intensificação Ecológica da Agricultura (IEA)

Novos sistemas agrícolas são necessários para permitir que a agricultura satisfaça cada vez mais as diversas expectativas da sociedade. Durante décadas, a agronomia tem produzido conhecimento e projetado agroecossistemas para maximizar a produção de alimentos e fibras primárias, quer para consumo direto ou para uso industrial. As questões de produção agrícola recentemente expandiram para incluir outros serviços ecossistêmicos (ZHANG et al., 2007).

Estudos têm demonstrado que as visões multidisciplinares da agricultura poderiam ser melhores alcançadas por meio de uma melhor utilização dos mecanismos de regulação biológica em diferentes níveis: manejo da cultura, desenhos dos sistemas de cultivos, arranjo e manejo da paisagem (MATSON et al., 1997; MÉDIÈNE et al., 2011). Deste modo, nas últimas décadas, muito tem se discutido sobre a sustentabilidade da produção de alimentos e resiliência em uma nova ordem política, em função do aumento dos preços dos alimentos com certa volatilidade e aumento da demanda. A produção e disponibilidade de alimentos afeta o conjunto biofísico, econômico, social e fatores políticos com complexas interações que definem o que comemos (GODFRAY et al., 2011).

A pressão constante sobre a produção agrícola, a lida com um ambiente cada vez mais degradado, com incertezas resultantes das alterações climáticas e com a necessidade de adaptar os sistemas de cultivo a esta realidade, demonstra a importância da intensificação sustentável da produção de culturas, pois essa proporciona oportunidades para otimizar a produção de alimentos por unidade de área, levando em consideração uma gama de aspectos da sustentabilidade, incluindo os impactos sociais, políticos e ambientais (FAO, 2014).

Em resposta aos impactos causados pelos sistemas agrícolas tradicionais, a IEA tem sido sugerida (BONNY, 2011; DORÉ et al., 2011; MALEZIEUX, 2012) como um modelo agrícola que propõe aumentar os produtos agrícolas (alimentos, fibras, agro-combustíveis e serviços ambientais) por unidade de área, reduzindo o uso e a necessidade de inputs externos (agrotóxicos, combustível). Assim, capitalizam-se processos que suportam e regulam a produtividade primária em agroecossistemas, além de melhorar a segurança alimentar, a preservação de habitats naturais e biodiversidades, a proteção do sistema climático e diminuir os gaps de rendimento das culturas (CASSMAN, 1999; CASSMAN et al., 2003; TITTONEL et al., 2013).

A IEA busca também solucionar o gap de rendimento das produtividades das culturas cultivadas, que é estimado pela diferença entre o potencial de rendimento da cultura e a média atingida pelos agricultores, numa escala de interesse temporal e espacial específico. O potencial de rendimento, por sua vez, pode ser definido e mensurado de várias maneiras (LOBELL et al, 2009). Entretanto, ressalta-se que as melhorias no rendimento das culturas podem ocorrer de forma lenta até atingir a demanda dos produtos agrícolas, pois o aumento do potencial de rendimento varia largamente em todo o mundo, variando também o gap, diferença entre o potencial e o rendimento atual (RAY et al., 2013, SCHIERHORN et al., 2014).

Com a diferença no gap de rendimento e o crescimento populacional, é cada vez maior o fosso entre ricos e pobres e a degradação ambiental. Desse modo, uma reavaliação do uso e alternativas de energia irão moldar a vida no século 21. Mas, enquanto os sistemas agrícolas crescem para atender às demandas de mais pessoas, o aumento da pressão será colocado sobre os recursos naturais. A competição por terra, água e recursos energéticos dos setores urbano e industrial, se torna mais aguda e as terras disponíveis permanecem estáticas ou encolhem (DORAN, 2002).

Sérias preocupações sobre a degradação ambiental, resultante de formas intensivas de uso da terra - que excedem a capacidade de carga ecológica -, têm sido amplamente divulgadas, o que gerou interesse na avaliação da qualidade e da saúde dos recursos do solo. Isso tendo sido estimulado pelo aumento da consciência de que o solo é um componente extremamente importante da biosfera da terra e do funcionamento não só da produção de alimentos e fibras, mas também da manutenção da qualidade local, regional e ambiente global (OLDEMAN, 1994; GLANZ, 1995).

É preciso determinar quais fatores de manejo do solo e das culturas influenciam no crescimento e desenvolvimento das plantas ao longo do seu ciclo de crescimento, a fim de se poder incorporar princípios e práticas agrícolas que aumentem o rendimento das culturas, minimize a degradação dos solos, sustentem a produção de alimentos na mesma área e sejam favoráveis ao aumento ou manutenção da biodiversidade e serviços ambientais. Em solos agrícolas, o desempenho das culturas cultivadas tende a ser maximizado e a degradação do solo e do meio ambiente tendem a ser minimizado, quando os parâmetros indicadores de qualidade física do solo estão dentro de suas faixas ideais (REYNOLDS et al., 2008).

2.3 Indicadores Físicos do Solo

O conhecimento dos valores dos indicadores físicos pode contribuir na escolha dos sistemas de manejo e consequente melhoria na qualidade do solo, no rendimento e crescimento das culturas. Alguns dos indicadores mais importantes na avaliação da qualidade do solo são: resistência à penetração, densidade de raiz, umidade do solo, densidade do solo, porosidade total, macroporosidade e volume de água saturado (REYNOLDS et al., 2007; DEXTER et al., 2004 a,b,c).

Os indicadores físicos de qualidade do solo variam de diferentes maneiras de acordo com o solo e o sistema de manejo. Exemplo de solo com qualidade física insuficiente pode ser representado por indicadores que apresentam uma ou mais das seguintes características: baixa infiltração de água, escoamento de água na superfície, coesão, má aeração, baixa enraizabilidade, e baixa trabalhabilidade (REICHERT et al., 2009).

A resistência à penetração (RP) afeta diretamente o crescimento das plantas por dificultar o desenvolvimento das raízes, o que resulta na diminuição do transporte de água, nutrientes e rendimento das culturas. A resistência é influenciada pela umidade e pela densidade do solo, sendo correlacionada positiva e exponencialmente com a umidade do solo (HÅKANSSON et al., 2000). Esse indicador de qualidade física do solo permite a identificação de valores potencialmente limitantes ao crescimento das raízes, além de possibilitar o estabelecimento de valores críticos de umidade e de densidade do solo (TORMENA et al., 1999). Para a maioria das culturas agrícolas, o desenvolvimento do sistema radicular diminui drasticamente quando há resistência à penetração superior a 2 MPa (TAYLOR et al., 1966).

O bom crescimento e funcionamento da raiz requerem uma adequada aeração e capacidade de armazenamento de água pelo solo, além de baixa densidade ou resistência (REYNOLDS et al., 2008). O comprimento de raiz é uma zona específica ou a massa no campo todo, definida como um importante parâmetro na estimativa da absorção de água e nutrientes pelas culturas (ZHUANG et al., 2001).

O crescimento e o rendimento final das culturas são claramente relacionados à distribuição das raízes, que determinam a absorção e utilização de água e nutrientes (YANG GAO et al., 2010). Sua profundidade é particularmente benéfica por permitir a absorção de água em camadas mais profundas do solo durante períodos de seca (MCKENZIE et al., 2009; GAISER et al., 2012). A extensão e distribuição das raízes podem ser expressas como densidade do comprimento radicular ou o peso de raiz, que poderá ser influenciado pela densidade do solo (ADIKU et al., 2001).

A densidade do solo é um atributo que pode ser usado como parâmetro de qualidade física para determinar os poros médios e descrever a compactação do solo. A compactação presente nos solos devido a processos naturais ou tráfico de maquinários agrícolas causa uma redução do volume total de poros, principalmente os maiores. Este fator reduz significativamente a infiltração, distribuição das raízes e drenagem de água pelo solo, favorecendo os processos de erosão, com um grande impacto ambiental (FLEIGE et al., 2000; REYNOLDS et al., 2002; GREGORY, 2006).

Os valores absolutos de densidade do solo não são adequados para a caracterização de compactação do solo em relação ao rendimento de culturas quando se comparam diferentes solos, pois os limites ideais e críticos de densidade para o crescimento das culturas dependem fortemente da classe de solo, ou seja, são diferentes os valores ideais de densidade do solo para as diferentes classes de solo (REICHERT et al., 2009). Se o solo é compactado, a densidade aumenta e a porosidade diminui (KELLER et al., 2010).

A porosidade é a fração do volume total do solo que é tomado por espaço poroso. Assim, é um valor único de quantificação a quantidade de espaço disponível para o fluido no interior do solo (NIMMO, 2004). Os espaços porosos do solo determinam seu funcionamento. Por exemplo, o transporte de água e gases ocorrem por meio de espaços porosos conectados, enquanto a friabilidade do solo, que permite a sua desagregação durante o preparo, requer a existência de poros na forma de microfissuras (DEXTER et al., 2008).

Um aspecto comum entre os indicadores é que eles expressam direta ou indiretamente o volume ou função do espaço poroso no solo. A densidade e a macroporosidade são funções óbvias do volume de poros. Portanto, identificar o volume ótimo de poros e sua função no solo pode melhorar a compreensão entre a qualidade física do solo, o impacto ambiental dos sistemas de manejo, a produtividade das culturas e a dinâmica de água e solutos no perfil do solo (REYNOLDS et al., 2009).

O aumento no teor de água reduz a aeração, a resistência do solo à penetração e a dinâmica desses fatores provoca interações que regulam o crescimento e funcionamento das raízes, o que torna necessário o entendimento dessas relações (REICHERT at al., 2003). Para as plantas conseguirem se desenvolver, absorver os nutrientes e utilizá-los de forma eficiente, é imprescindível o uso de práticas que minimizem a recompactação do solo, o que melhora a enraizabilidade das plantas, a aeração, infiltração e, consequentemente, a eficiência do uso de nutrientes (MOURA et al., 2008).

2.4 Eficiência do Uso de Nutrientes

A eficiência do uso dos nutrientes (EUN) pode ser definida como o rendimento por unidade de *inputs* ou rendimento de produto por conteúdo de nutriente aplicado. Melhorar a EUN é um pré - requisito essencial para expansão da produção das culturas agrícolas em solos com baixa disponibilidade de nutrientes, e isto depende não somente da habilidade da planta em absorver os nutrientes do solo, mas também do seu transporte, armazenamento e utilização (GRAHAM et al., 1984; CENTRE, 2014).

Uma estratégia para incrementar a eficiência do uso de nutrientes em solos coesos do trópico úmido deve incluir o aumento do crescimento de raiz e a melhoria do ambiente edáfico com adição de adubos de liberação lenta, sincronizando com a demanda das plantas. De tal modo que, práticas consideradas sustentáveis - como o plantio direto, a aplicação de compostagem e biomassa, uso de biossólidos, sistemas agroflorestais e cobertura superficial com leguminosas - podem ser utilizadas na tentativa de aumentos de produtividade (LAL, 2009; MOURA et al., 2012).

A prática do plantio direto na palha de leguminosas apresenta vantagens que podem contribuir para os incrementos de produtividade em solos tropicais, pois permite a reciclagem de nutrientes, melhora a qualidade dos indicadores físicos do solo, aumenta a capacidade de aeração, reduz o impacto causado pelas gotas de chuva e fornece moderadas quantidades de nutrientes (BECHER et al., 1997; ADEKALU et al., 2006; MOURA et al., 2013). Ademais, a adição de resíduos de plantas como cobertura do solo também diminui resistência à penetração e aumenta o conteúdo de água no solo porque conserva a umidade e reduz as perdas por evaporação (MOURA et al., 2012).

Pesquisas realizadas por Moura et al (2010) e Aguiar et al (2010) na região do trópico úmido demonstraram que a combinação dos resíduos de leguminosas de alta qualidade (*Leucaena leucocephala* - alta velocidade de decomposição) com outra de baixa qualidade (C*litoria fairchildiana* - baixa velocidade de decomposição) promove uma liberação de nutrientes sincronizada com as necessidades nutricionais da cultura, ao mesmo tempo em que garante a proteção do solo durante o cultivo. A combinação dessas espécies é mais eficiente para sustentar condições de crescimento das culturas. Esta eficiência é relacionada a dois fatores: primeiro, o padrão dessas espécies de leguminosas permite maior absorção de nutrientes pelas raízes e a concentração de nutrientes nos resíduos; segundo, a alta taxa de remobilização de nutrientes que derivam da sua decomposição (VANLAUWE et al., 2005).

Mesmo com a adição de resíduos de leguminosas na superfície do solo sendo recomendada para melhorar a enraizabilidade do solo, em profundidade a influência é baixa, não ultrapassando a camada de 10 cm (COOK et al., 2006, MOURA et al., 2013). Portanto, além do plantio direto na palha de leguminosas, outras práticas são necessárias para aumentar o sistema radicular em profundidade e consequentemente aumentar a absorção de nutrientes, tal qual o uso do gesso.

O gesso agrícola ($CaSO_4.2H_2O$) aplicado na superfície do solo, é recomendado como alternativa para a melhoria do ambiente radicular, em decorrência do aumento da concentração de cálcio, compensando o reduzido efeito do calcário no subsolo,uma vez que o gesso é mais solúvel que o calcário (SUMNER et al., 1986; SUMNER, 1995; CARVALHO et al.,1997; CAIRES et al., 2003). Movimenta-se ao longo do perfil sob a influência da percolação de água, não afeta o pH e reduz a toxidez de Al^{3+} no subsolo (CAIRES et al., 1999, 2003).

O gesso também atenua a coesão do solo e aumenta a distribuição do sistema radicular promovendo o acesso à água, o que geralmente se reflete em aumento de rendimento em muitas culturas (REEVE et al., 1972; RADICLIFFE et al., 1986; FARINA et al., 2000; SUMNER, 2011; CAIRES et al., 2011). Nessa perspectiva, espera-se que o plantio direto na palha de leguminosas associado ao uso do gesso agrícola seja eficiente na melhoria dos indicadores físicos do solo, no uso de nutrientes e na redução da diferença entre o potencial de produção das culturas e o que é produzido pelos agricultores na região do trópico úmido.

Portanto, em meio ao aumento da demanda por alimentos e a necessidade de continuar produzindo na mesma área, é fundamental o uso racional e eficiente dos nutrientes. A adoção de práticas agrícolas associadas pode contribuir para melhoria no uso de nutrientes pelas culturas agrícolas, sobretudo daqueles, como o fósforo e nitrogênio, essenciais ao desenvolvimento das plantas.

2.5 Eficiência de Recuperação do Fósforo

O fósforo (P) é um nutriente essencial para plantas, animais e seres humanos, logo sua deficiência é considerada um dos maiores fatores limitantes de produtividade das culturas, especialmente nos trópicos e subtrópicos (RAMAEKERSA et al., 2010; MA et al., 2011). O fósforo existe na crostra da terra sob a forma de rocha fosfatada, e é somente por meio dos processos de intemperismo e lixiviação que é mobilizado em sistemas terrestres. A taxa relativamente lenta com que ocorrem esses dois processos tem sido um dos obstáculos mais importantes à produtividade primária terrestre (RAVEN, 2008).

Embora ainda haja muito debate a respeito da longevidade das reservas de fosfato, cientistas e indústria concordam que há uma forte necessidade de aumento da reciclagem e utilização eficiente de fósforo em todo o sistema alimentar. Há um interesse de identificar e comparar sistematicamente medidas que podem produzir resultados no sentido da segurança de fósforo (MWETA et al., 2007; BEKUNDA et al., 2011). Foi apenas ao longo dos últimos 50 anos que a intervenção humana no ciclo de fósforo aumentou drasticamente, afim de lidar com o aumento sem precedentes da demanda por alimentos em função de um rápido crescimento da população global (SMIL, 2000; TILMAN et al., 2002).

Ademais, os fertilizantes fosfatados são de alto custo, porque são produzidos a partir de fontes minerais fosfatadas limitadas e o seu uso em excesso pode destruir o equilíbrio ecológico e resultar em danos ambientais graves, como exemplo a eutrofização de rios. (QUAN et al., 2002; ZHANG et al., 2005). Para reduzir tais danos, há que se desenvolver sistemas agrícolas com base na eficiência de uso dos nutrientes, pois há uma crescente escassez de rocha fosfática e a dependência da produção mundial de alimentos sobre a disponibilidade de P (VACARI, 2009).

A mitigação do uso dos recursos de P pode ser feita por meio do aumento da disponibilidade de rocha fosfática pela melhor exploração e tecnologia de mineração, e pela melhoria da eficiência do uso de fósforo por humanos, deste modo poderá reduzir o *input* de fertilizantes fosfatados (SUH et al., 2011). O principal método para beneficiar a aplicação, bem como disponibilizar o P fixado, é aumentar seu contato com o sistema radicular da planta para aumentar sua aquisição pela planta (WISSUAWA, 2003).

Nesse cenário, os sistemas agrícolas devem adotar medidas que aumentem a disponibilade de P para as plantas, dentre essas, a adição de materiais orgânicos ao solo pode influenciar a disponibilidade de P, com redução da capacidade de sorção de P nos solos, permitindo assim, uma utilização mais completa de P do solo pelas plantas (NZIGUHEBA et al., 1998, MWETA., et al 2007). Dada a importância do P para a sustentabilidade da agricultura e segurança alimentar mundial, a garantia da utilização equilibrada dos recursos de P é importante para que suas perdas sejam minimizadas.

REFERÊNCIAS BIBLIOGRÁFICAS

ADEKALU, K., OKUNADE, D., OSUNBITAN, J. 2006. Compaction and mulching effects on loss and runoff from two southwestern Nigeria agricultural soils.**Geoderma**, v. 137, p. 226-230.

ADIKU, S. G. K., OZIER-LAFONTAINE, H., BAJAZET, T. 2001. Patterns of root growth and water uptake of a maize – cowpea mixture grown under greenhouse conditions. **Plant and Soil**.v. 235, p. 85–94.

BEKUNDA, M.; CORDELL, D.; CORMAN, J.; ROSEMARIN, A.; SALCEDO, I.; SYERS, K.; LOUGHEED, T. 2011. **Phosphorus & Food Production**, UNEP Yearbook: Emerging Issues in Our Global Environment, 2011; United Nations Environment Programme (UNEP): Paris, France.

BONNY, S., 2011. Ecologically intensive agriculture: nature and challenges. **Cahiers Agricultures**, v. 20, p. 451–462.

AGUIAR, A. C. F., SOUZA, E. A., SILVA, A. J. C., MOURA, E. G. M. 2014. Enhancement of nitrogen use efficiency to increase yield and maize grain quality in no-till systems. **Tropentag 2014**, Prague, Czech Republic September 17-19.

AGUIAR, A. C. F., BICUDO, S. J., SOBRINHO, J. R. S. C., MARTINS, A. L. S., COELHO, K. P., MOURA, E. G.2010. Nutrient recycling and physical indicators of alley cropping system in sandy loam in the pre-Amazon region of Brazil. **Nutrient Cycling In Agroecosystems**, v.86, p. 189-198.

AGUIAR, A. C. F., AMORIM, A. P., COELHO, K.P., MOURA, E. G. 2009. Environmental and agricultural benefits of a management system designed for sandy loam soils of the humid tropics. **Revista Brasileira de Ciência do Solo**,v.33, p.1473-1480.

AGUIAR, A. C. F. **Sustentabilidade do sistema plantio direto em Argissolo no trópico úmido**. Botucatu, Universidade Estadual Paulista, 2006. 57p. (Tese de Doutorado).

BECHER, H. H., BREUER, J., KLINGER, B. 1997. An index value for characterizing hardsetting soils by fall-cone penetration. S**oil Technology**, v.10, p.47-56, 1997.

BUSSCHER, W.J, BAUER, P. J., FREDERICK, J. R.2002. Recompaction of the coastal loamy sand after deep tillage the function of subsequent cumulative rainfall. **Soil & Tillage Research** ; v.68, p.49-57.

CARVALHO, M. C. S., VAN RAIJ, B. 1997. Calcium sulphate, phosphogypsum and calcium carbonate in the amelioration of acid subsoils for root growth. **Plant and Soil**, v.192, p.37–48.

CASSMAN, K. G., DOBERMANN, A., WALTERS, D.T., YANG, H. 2003. Meeting cereal demand while protecting natural resources and improving environmental quality. **Annual Review of Environment and Resources,** v. 28, p.315–58.

CASSMAN, K. G. 1999. Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. **Proceedings of the National Academy of Sciences ,**USA 96: p.5952–59

CAIRES, E. F., JORIS, H. A. W., CHURKA, S. 2011. Longterm effects of lime and gypsum additions on no-till corn and soybean yield and soil chemical properties in southern Brazil. **Soil Use and Management,** v. 27, p. 45-53.

CAIRES, E. F.; BLUM, J.; BARTH, G.; GARBUIO, F. J; KUSMAN, M. T. 2003.Alterações químicas do solo e resposta da soja ao calcário e gesso aplicados na implantação do sistema de plantio direto. **Revista Brasileira de Ciência do Solo**, v. 27: p. 275-286.

CAIRES, E. F.; FONSECA, A. F.; MENDES, J.; CHUEIRI, W; MADRUGA, E.F.199. Produção de milho, trigo e soja em função das alterações das características químicas do solo pela aplicação de calcário e gesso na superfície, em sistema de plantio direto. **Revista Brasileira de Ciência do Solo**,v. 23: p.315-327.

CENTRE, J. I. **Nutrient use efficiency 2014.** Disponível em: https://www.jic.ac.uk/staff/stanislav-kopriva/nutrient_use_efficiency.htm, Acesso: 01 dezembro 2014.

COOK, R. J., VALDEZ, G. S. B., LEE, H. C. 2006. Mulch effects on rainfall interception, soil physical characteristics and temperature under Zea mays L. **Soil Tillage Research**, v.91, p.227–235.

DEXTER, A. R. 2004 a. Soil physical quality. **Soil & Tillage Research**, v.79, p. 129–130.

DEXTER, A. R. 2004 b. Soil physical quality: Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. **Geoderma**, v.120, p. 201–214.

DEXTER, A. R. 2004 c. Soil physical quality: Part II. Friability, tillage, tilth and hard-setting. **Geoderma,** v. 120, p. 215–225.

DEXTER, A. R., CZYŻ, E. A., RICHARD, G., RESZKOWSKA, A. A. 2008. User-friendly water retention function that takes account of the textural and structural pore spaces in soil. **Geoderma,** v. 143, p.243–253.

DORAN, J. W. 2002. Soil health and global sustainability: translating science into practice. **Agriculture, Ecosystems & Environment**,v. 88, p. 119–127.

DORÉ, T., CADORET, K., MAKOWSKI, D., MALÉZIEUX, E., MUNIER-JOLAIN, N., TCHAMITCHIAN, M., TITTONELL, P. 2011. Facing up to the paradigm of ecological intensification in agronomy: revisiting methods, concepts and knowledge. **European. Journal Agronomy,** v. 34, p. 197–210.

FARINA, M. P. W., CHANNON, P., THIBAUD, G. R. 2000. A comparison of strategies for ameliorating subsoil acidity: II. Longterm soil effects. **Soil Science Society of America Journal**,v. 64,p. 652

FAO 2014, **Sustenaible Crop Production Intensification**,.Disponível em : http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/en/ Acesso em: 29 de novembro de 2014.

FERRAZ, JR. A. S. L. O cultivo em aleias como alternativa para a produção de alimentos na agricultura familiar do tropico umido. In: MOURA, E. G. (org). **Agroambientes de transição- Entre o tropico umido e o semi-árido do Brasil**. Atributos; alterações; uso na produção familiar. São Luis: UEMA. p. 71-100. 2004.

FLEIGE, H., HORN, R. 2000. Field experiments on the effect of soil compaction on soil properties, runoff, interflow and erosion. **Advances in GeoEcology,** v.32, p. 258–268.

GAISER, T., PERKONS, U., KU¨PPER, P. M., PUSCHMANN, D. U., PETH, S., 2012. Evidence of improved water uptake from subsoil by spring wheat following lucerne in a temperate humid climate. **Field Crops Research** ,v.126, p. 56–62.

GLANZ, J.T., 1995. Saving Our Soil: Solutions for Sustaining Earth's Vital Resource. **Johnson Books**, Boulder, CO, USA.

GRAHAM, R. D. 1984. Breeding for nutritional characteristics in cereals. p. 57– 102. In P. B. Tinker and A. Lauchli (eds.), **Advances in Plant Nutrition,** v. 1, Praiger Publisher, New York, NY.

GREGORY, P. J., 2006. Roots, rhizosphere and soil: the route to a better understanding of soil science? **European Journal Soil Science**. v. 57, p. 2–12.

GEHRING, C., MOURA, E. G., SANTOS, R. R. S., AGUIAR, A. C. F., SOUSA, A. M. B., BODDEY, R. M. 2013. Ecological intensification of rice production in the lowlands of Amazonia-options for smallholder rice producers. **European Journal of Agronomy**, v. 46, p.25-33.

GODFRAY, H., CHARLES, J. 2011. Proceedings of the national academy of sciences of the United States of America. **Food for Fhought** , v.108.

HÅKANSSON, I., LIPIEC, J. 2000. A review of the usefulness of relative bulk density values in studies of soil structure and compaction. **Soil & Tillage Research**.v.53, p. 71–85.

HOCHMAN, Z., CARBERRY. P. S., 2011. Emerging consensus on desirable characteristics of tools to support farmers management of climate risk in Australia. **Agricultural Systems**. v. 104, p. 441- 450.

KELLER,T., HÅKANSSON, I. 2010. Estimation of reference bulk density from soil particle size distribution and soil organic matter content. **Geoderma**,v.154, p. 398-406.

LAL, R. 2009. Soil degradation as a reason for inadequate human nutrition. **Food Security**, v.1: p. 45-57.

LOBELL, D. B., CASSMAN, K. G., FIELD, C.B. 2009. Crop yield gaps: their importance, magnitudes and causes. **Annual Review of Environment and Resources**. v. 34, P.179-204.

MA, W., MA, L., LI, J., WANG, F., SISÁK, I., ZHANG, F. 2011. Phosphorus flows and use efficiencies in production and consumption of wheat, rice, and maize in China. **Chemosphere** ,v. 84, p.814–821.

MALEZIEUX, E. 2012. Designing cropping systems from nature. **Agronomy for Sustainable Development** ,v.32. p. 15–29.

MATSON, P. A., PARTON, W. J., POWER, A. G., SWIFT, M. J. 1997. Agricultural intensificationand ecosystem properties. **Science,** v. 277, p. 504–509.

MÉDIÈNE, S., VALANTIN-MORISON, M., SARTHOU, J.-P., DE TOURDONNET, S., GOSME, M., BERTRAND, M., ROGER-ESTRADE, J., AUBERTOT, J.-N., RUSCH, A., MOTISI, N., PELOSI, C., DORÉ, T. 2011. Agroecosystem management and biotic interactions: A review. **Agronomy for Sustainable Development**, v. 31, p.491–514.

MI, G.; CHEN, F.; ZHANG, F. Physiological and genetic mechanisms for nitrogen-use efficiency in maize. **Journal of Crop Science and Biotechnology,** v.10, n.2, p. 57-63, 2007.

MWETA DE, AKINNIFESI FK, SAKA JDK, MAKUMBA W, CHOKOTHO N. 2007. Green manure from phosphorus adsorption and uptake by maize crop in a gliricidia-maize intercropping. **Science Research**. Essays. 2:446–453.

MOURA, E.G., SENA, V.G., CORRÊA, M.S., AGUIAR, A.C.F. 2013. The importance of an alternative for sustainability of agriculture around the periphery of the Amazon rainforest**. Recent Patents Food Nutrition & Agriculture.**v.5, p.70-78.

MOURA, E. G., OL IVEIRA, A. K., COUTINHO, C.G., PINHEIRO, K. M., AGUIAR, A. C. F. 2012. Management of a cohesive tropical soil to enhance rootability and increase the efficiency of nitrogen and potassium use. **Soil Use and Management.** v. 28, P.368-375.

.

MOURA, E. G., SERPA, S. S., SANTOS, J. G. D., COSTA SOBRINHO, J. R. S., AGUIAR, A.C.F. 2010. Nutrient use efficiency in alley cropping systems in the Amazonian periphery. **Plant and Soil**, v. 335, p.363-371.

MOURA, E. G., MOURA, N. G., MARQUES, E. S., PINHEIRO, K. M., COSTA SOBRINHO, J. R. S., AGUIAR, A. C.F. 2009 a. Evaluating chemical and physical quality indicators for a structurally fragile tropical soil. **Soil and Use Management**, v.25, p. 368-375.

MOURA, E. G., ARAÚJO, J. R. G., MONROE, P. H. M.; O. NASCIMENTO, I.O.; AGUIAR, A. F. C. 2009 b. Patents on periphery of the Amazon rainforest. **Recent Patents on Food, Nutrition & Agriculture**, v.1, p.142-149.

MOURA, E G, ALBUQUERQUE, J. M, AGUIAR, A. C. F. 2008. Growth and productivity of corn as affected by mulching and tillage in alley cropping systems. **Scientia Agricola**. v.65: p.204-8.

MOURA, E.G., MONROE, P. H. M., COELHO, M. J. A., COSTA SOBRINHO, J. R. S., AGUIAR, A. C. F., 2013. Effectiveness of calcined rock phosphate and leucaena prunings as a source of nutrientes for maize in a tropical soil. **Biological Agricuture & Horticuture**. v. 29, p.132–144.

MCKENZIE, B. M., BENGOUGH, A. G., HALLETT, P .D., THOMAS, W. T. B., FORSTER, B., MCNICOL, J.W. 2009. Deep rooting and drought screening of cereal crops: a novel fieldbased method and its application. **Field Crops Research**.v.112, p.165–171.

NIMMO, J. R., 2004, Porosity and Pore Size Distribution, in Hillel, D., ed. **Encyclopedia of Soils in the Environment**: London, Elsevier, v. 3. p. 295-303.

NZIGUHEBA G, PALM CA, BURESH RJ, SMITHSON PC 1998. Soil Phosphorus fractions and adsorption by organic and inorganic sources. **Plant and Soil** ,v. 198: 159-161

OLDEMAN, L. R., 1994. The global extent of soil degradation. In: Greenland, D.J., Szabolcs, I. (Eds.), **Soil Resilience and Sustainable Land Use**. CAB International, Wallingford, p. 99–118.

QUAN, W. M, YAN, L. 2002. Effects of Agricultural non-point source pollution on eutrophication of water body and its control measure. **Acta Ecologica Sinica**, v. 22, p. 291-299.

RADCLIFFE, D. E., CLARK, R. L., SUMNER, M. E. 1986. Effect of gypsum and deep-rooting perennials on subsoil mechanical impedance. **Soil Science Society America Journal,** v.50, p.1566-1570.

RAMAEKERSA, L., REMANSB, R., RAOC, I. M., BLAIR, C. M. W., VANDERLEYDEN, J. 2010. Strategies for improving phosphorus acquisition efficiency of crop plants. **Field Crops Research,** v.117, p. 169–176.

RAVEN, J.A., 2008. **Phosphorus and the future** 271–283. In: White, P.J., Hammond, J.P. (Eds.), The Ecophysiology of Plant-Phosphorus Interactions. Springer, Dordrecht.

RAY, D. K., MUELLER, N. D., WEST, P. C., FOLEY, J. A. 2013 .Yield trends are insufficient to double global crop production by 2050. **Plosone.org .**8 e66428.

REICHERT, J. M., REINERT D. J., BRAIDA, J. A. 2003. **Manejo, qualidade do solo e sustentabilidade: condições físicas do solo agrícola**. CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 29. Ribeirão Preto.Palestras. Ribeirão Preto: SBCS,2003 (CD-ROM).

REICHERT, J. M., SUZUKI, L. E. A. S., REINERT, D. J., HORN, R., HÅKANSSON, I. 2009. Reference bulk density and critical degree-of-compactness for no-till crop production in subtropical highly weathered soils. **Soil & Tillage Research**, v.102 , p. 242–254.

REEVE, N. G., SUMNER, M. E. 1972. Amelioration of subsoil acidity in Natal Oxisols by leaching of surface applied amendments. **Agrochemophysica**, v.4, p.1-6.

REYNOLDS, W., BOWMAN, B., DRURY, C., TAN, C., LU, X. 2002. Indicators of good soil physical quality: density and storage parameters .**Geoderma**, v. 110, p. 131–146.

REYNOLDS, W.D., DRURY, C.F., YANG, X.M., FOX, C.A., TAN, C.S., ZHANG, T.Q., 2007. Land management effects on the near-surface physical quality of a clay loam soil. **Soil & Tillage Research**,v. 96, p. 316–330

REYNOLDS,W. D., DRURY, C.F., YANG, X.M., TAN, C.S. 2008. Optimal soil physical quality inferred through structural regression and parameter interactions. **Geoderma**, v.146 p. 466–474.

REYNOLDS, W.D., DRURY, C.F., TAN, C.S., FOX, C.A., YANG, X. M. 2009. Use of indicators and pore volume-function characteristics to quantify soil physical quality. **Geoderma**,v. 152 , p. 252–263.

SMIL, V., 2000. Phosphorus in the environment: Natural flows and human interferences. **Annual Review Energy Environment**.v. 25, 53–88.

SUH, S., YEE, S. 2011. Phosphorus use-efficiency of agriculture and food system in the US. **Chemosphere** ,v. 84, p. 806 – 813.

SUMNER, M. E. 1995. Amelioration of subsoil acidity with minimum disturbance. In: Subsoil management techniques (eds N.S. Jayawardane & B.A. Stewart), p. 147–185. **Lewis Public, Athens.**

SUMNER, M. E., SHAHANDEH, H., BOUTON, J., HAMMEL, J. 1986. Amelioration of an acid soil profile through deep liming and surface application of gypsum. **Soil Science Society of America Journal**, v. 50, p. 1254–1258.

SUMNER, M. E. 2011 .Out of sight out of mind: subsurface factors in sugarcane yield decline. 84th SASTA Congress,(2011), África, **Professional South African Sugar Technologists' Association** 84: p. 1 – 27.

SCHIERHORN, F., FARAMARZI, M., PRISHCHEPOV, A. V, F. J., MÜLLER, D. 2014. Quantifying yield gaps in wheat production in Russia. **Environmental Research Letters.** V.9.

TAYLOR, H. M., ROBERSON, G. M., PARKER, J. J. J.1966. Soil Strength-Root Penetration Relations for Medium- to Coarse-Textured Soil Materials. **Soil Science**, v.102, p. 18-22.

TORMENA, C. A., SILVA, A. P., LIBARDE, P. L.1999. Soil physical quality of a Brazilian Oxisol under two tillage systems using the least limiting water range approach. **Soil & Tillage Research**, v. 52, p. 223-232.

TILMAN, D., CASSMAN, K.G., MATSON, P.A., NAYLOR, R., POLASKY, S., 2002. Forecasting agriculturally driven global environmental change. **Science**,v. 418, 671–677.

TITTONELL, P. A, KEN, E. GILLER, B. 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. **Field Crops Research.**v. 143, p. 76–90.

VACCARI, D.A., 2009. Phosphorus: a looming. **Scientific American**,v. 6, p.54–59.

VANLAUWE, B., DIELS, J., SANGINGA N., MERCKX, R. 2005. Long-term integrated soil fertility management in South-western Nigeria: crop performance and impact on the soil fertility status. **Plant and Soil**, v. 273: p. 337-54.

YANG, G., DUANA, A., QIUA, D. X., LIUA, Z., SUNA, ZHANGA, J., WANG, H. 2010. Distribution of roots and root length density in a maize/soybean strip intercropping system. **Agricultural Water Management.** v. 98, p. 199–212.

ZHANG L M., HE, L. Y., LI, J.S., XU S Z. 2005. Phosphorus nutrient characteristics of different maize inbreds with tolerance to low-P stress. **Scientia Agricultura Sinica**, v.38, p. 110-115.

ZHANG, W., RICKETTS, T.H., KREMEN, C., CARNEY, K., SWINTON, S.M., 2007. Ecosystem services and dis-services to agriculture. **Ecological Economics**. V.64, p. 253–260.

ZHUANG, J., YU, G. R., NAKAYAMA, K. 2001. Scaling of root length density of maize in the field profile.J. **Plant and Soil**, v. 235, p. 135–142.

ZHUANG, J., NAKAYAMA, K., YU, G. R., URUSHISAKI, T. 2001 Estimation of root water uptake of maize: an ecophysiological perspective. **Field Crops Research**.v.69, p. 201–213.

WISSUWA, M., 2003. How do plants achieve tolerance to phosphorus deficiency? 727 Small causes with big effects. **Plant Physiology**.v.133, 1947-1958.

ENHANCEMENT OF THE ROOTABILITY OF A STRUCTURALLY FRAGILE TROPICAL SOIL USING GYPSUM AND LEGUMINOUS RESIDUES

CAPÍTULO II

Artigo escrito de acordo com as normas da revista Soil Use and Management

Enhancement of the rootability of a structurally fragile tropical soil using gypsum and leguminous residues

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Abstract

In humid tropics regions, a combination of factors related to soil rootability conditions contribute to reductions in nutrient use efficiencies. The aim of this work was evaluate the combined effects of the application of gypsum and mulch from leguminous trees on soil rootability in the root zone, root growth and phosphorus recovery efficiency in maize planted in a sandy loam soil prone to cohesion. The experiment was conducted in a randomised block design with four replications and the treatments: control, without residue and gypsum (C); leguminous residue (L); leguminous residue and 6 t/ha of gypsum (LG6); urea, 6 t/ha of gypsum (UG6); leguminous residue, urea and 6 t/ha of gypsum (LUG6); and leguminous residue, urea, and 12 t/ha of gypsum (LUG12). Gypsum plus leguminous residues can enhance the soil rootability when applied in tropical soils due to the combined effects of increased porosity and decreased penetration strength. These effects facilitate root growth in the deeper soil layers and promote phosphorus uptake. Application of crop residue increases the input and retention of calcium derived from the gypsum in the lower layers. The use of large amounts of gypsum with residue, despite a strong increase in phosphorus uptake by maize, did not result in a proportional increase in dry matter production. Given the small differences in calcium content between the treatments with 6 and 12 t/ha, parcelling the application of gypsum in combination with residue applications, rather than administering a single high dose, is recommended for tropical sandy loam soils with low cation retention capacitys.

Keywords: Nitrogen, phosphorus, nutrient use efficiency, sandy loam soil, cohesion

1Introduction

In the humid tropics region, small landholders often resort to the environmentally harmful practice of shift cultivation, mainly the slash-and-burn-fallow cycle, to establish a low-input agricultural system that is more convenient for resource-poor farmers (Brady & Weil, 1996). In many areas, high temperatures and rainfall, combined with soils derived from clastic sedimentary rocks, result in low nutrient availability and unfavourable conditions for continuous crop cultivation (Moura *et al.*, 2012). Under these circumstances, a combination of factors reduces the efficiency of nutrient use and, as a result, the manageability of sustainable agrosystems, even with fertilisation.

Most soils with low free iron and organic carbon levels exposed to repeated cycles of wetting and drying tend to undergo hardsetting, which decreases the rootable soil volume and impairs nutrient uptake (Mullins, 1999). The low cation retention capacity of the intensely weathered soils does not contribute to the retention of nutrients in the root zone (Dechert *et al.*, 2005). In addition, P is often a highly limiting factor in crop growth in weathered and acidic tropical soils with low available P and a high phosphate sorption capacity (Vance *et al.*, 2003). These factors are now recognised as the fundamental causes of deforestation and declining food security in small landholder farms in the Amazon region and its surroundings (Aguiar *et al.*, 2011). Therefore, the replacement of slash-and-burn agriculture by sustainable systems cannot succeed without an alternative approach that demonstrates the benefits of fertilisation. Thus, efficient nutrient use is necessary for ensuring the profitability and sustainability of crop systems in this region.

To enhance the environment of the root zone, no-tillage systems with surface covers such as mulch have been recommended by some authors. This practice has been recommended because a protective layer of residue absorbs raindrop impact and reduces evaporation from the soil surface and may delay hardsetting (Becher *et al.*, 1997). Unfortunately, this practice is an effective process only if there are no long intervals between rains (Ley *et al.*, 1995).

Another system that has been recommended is the continuous plant residues application, which improves the environment for root growth because it promotes the formation of unstable aggregates by increasing the free light fraction of organic matter, according to Shepherd *et al.* (2002). Furthermore, the continuous application of residues in no-till systems may enhance the soil structure to favour primarily P uptake, as reported by Moura *et al.* (2013), but it may confine organic matter additions to the upper soil surface and negate significant enhancement at lower soil depths. In this case, improvements in soil structural properties with crop residue mulch may only be significant near the soil surface (Blanco-Canqui & Lal, 2007). Additionally, Moura *et al.* (2013) observed that the direct effects of residues on soil attributes did not extend beyond 10 cm below the surface, which was not sufficient to produce enough root growth to adequately increase nutrient use efficiency and make fertiliser use profitable.

To extend rootability improvements to lower soil depths, several authors recommend the use of gypsum as a "flocculating" agent to improve soil structure by reducing the dispersion of the clay (Radcliffe *et al.*, 1986). The action of the dispersed clay in hardening or increasing soil strength is also decreased by applying gypsum (Sumner *et al.*, 1990). However, the application of gypsum, a readily available source of Ca^{2+}, can increase Ca ion activity in the liquid phase and the formation of insoluble Ca-P phases, thereby decreasing P availability and uptake (Kordlaghari & Rowell, 2006).

Therefore, we hypothesised that the use of gypsum combined cover crop residue may impart soil improvement effects to a deeper layer, improving the soil structure in the root zone and increasing root growth and nutrient uptake efficiency. The aim of this work was to evaluate the combined effects of gypsum and mulch from leguminous trees on soil rootability in the root zone, root growth and phosphorus recovery efficiency in maize grown in a sandy loam soil prone to cohesion.

2 Materials and Methods

2.1 Experimental site and trial set-up

The experiment was conducted during three growing seasons (2011, 2012 and 2013) at Maranhão State University, São Luiz, Brazil (2°30'S, 44°18'W). The region has a hot, 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 to June and a dry season with a pronounced water deficit from July to December. The local soil displayed hardsetting characteristics (Moura *et al.*, 2009), wich is classified as Arenic Hapludult, and consisted of 260 g/kg of coarse sand, 560 g/kg of fine sand, 80 g/kg of silt and 100 g/kg of clay.

The area had been fallow since 1990 and supported a native species of grass, which was removed using a glyphosate application. Lime and gypsum were applied by hand to the soil surface in December 2010. The lime was applied at a rate of 1 t/ha of calcium, which corresponds to 288.8 and 137.2 kg/ha of Ca and Mg, respectively. The gypsum was applied at a rate of 6 or 12 t/ha in the plots, which corresponds to 1,020 and 2,040 kg/ha of Ca, respectively. Residues from *Leucaena leucocephala* (leucaena) and *Clitoria fairchildiana* (clitoria) were collected from an area near the experimental site and applied at 6 t/ha (total of 12 t/ha), a rate similar to that commonly applied in alley cropping systems according to Aguiar *et al.* (2010). The quality parameters of the leucaena and clitoria residues were as follows: a C/N ratio of 12 and 23, N of 40.17 and 27.71 g/kg, P of 1.55 and 2.83 g/kg and Ca of 17.84 and 14.44 g/kg, respectively. The maize (cultivar AG 7088) was sown in the no-till system in January 2011, 2012 and 2013. A spacing of 80 cm between rows and 25 cm between plants was used. The maize was fertilised with 80 kg/ha of P_2O_5 from triple superphosphate (35 kg/ha of P), 80 kg/ha of K_2O from KCl and 5 kg/ha of Zn in the form of $ZnSO_4$. Triple superphosphate, urea, leguminous residues, zinc and KCl were applied in 2011, 2012 and 2013.

In January 2013, the experiment was analyzed following a randomised block design with four replications and the following treatments: control, without residue and gypsum (C); 12 t/ha of dry matter residue from legumes (L); 12 t/ha of dry matter residue from legumes and 6 t/ha of gypsum (LG6); 90 kg/ha of N from urea and 6 t/ha of gypsum (UG6); 90 kg/ha of N from urea, 6 t/ha of gypsum and 12 t/ha of dry matter residue from legumes (LUG6); and 90 kg/ha of N from urea, 12 t/ha of gypsum and 12 t/ha of dry matter residue from legumes (LUG12). The experiment was conducted under no-tillage conditions, and the experimental plot size was 4 x 8 m. Leucaena and clitoria residues were applied in the form of fresh branches. The total amount of urea and leguminous residue was divided, in two superficial applications one at sowing and another at the appearance of the fourth maize leaves.

2.2 Soil chemical analyses

Soil samples were taken for Ca analyses in November 2010 at depths of 0-10, 10-20, 20-30 and 30-40 cm, before lime and gypsum aplication and maize cultivation. Additional soil samples were collected in June 2013 at the finally of the rainy season at depths of 0-10, 10-20, 20-30 and 30-40 cm, and three replicates collected using a Dutch auger. The samples were passed through a 2 mm sieve and then air-dried prior to the analyses. Each sample was analysed using resin as an extractor for Ca, which was measured using a Varian 720 ES ICP

(Inductively Coupled Plasma) spectrometer, based on the standard techniques, according to Raij *et al.* (1986). To construct the graph of the estimated soil calcium content, a linear interpolation was used within the known range of data based on a critical level for tropical soil, defined by Ribeiro *et al.* (1999).

2.3 Soil physical analyses

The soil was sampled using 100 cm^3 rings, in May 2013, to determine soil dry bulk density and saturated volumetric water content, according to Thomasson (1978). Three replicates were collected at a depth of 8-12 cm. The samples were saturated, weighed, placed on a tension table and equilibrated at 6 kPa. After weighing, each replicate was oven dried at 105 °C. Soil dry bulk density (ρb) was calculated as m/v, where m is the dry collected soil mass at 105 °C and v is the ring volume. The saturated volumetric water content was determined by the difference between the saturated sample mass and the dry sample mass. The total porosity (φt) was calculated from the values of dry bulk density (ρb) and assumed particle density (ρp) as 2.65 t/m^3 using the following equation: $\varphi t = [1 - (\rho b / \rho p)]$, as defined in Aikins *et al.* (2012). The macro porosity was calculated as the difference between the saturated volumetric water content and the weight of the sample equilibrated at 6 kPa.

The soil moisture and penetration strength were measured at depths of 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm with three replicates per plot in July of 2013, after 3 days without rain. The penetration strength was measured using a digital penetrometer (Falker, Porto Alegre, Brasil) with 1 cm gradations, and 2.0 MPa was taken as the lower critical limit of recording (Silva & Kay, 1997). To construct the graph of the penetration strength, the mean of each depth was used (2.5 cm, 7.5 cm, 12.5 cm and 17.5 cm) with a simple interpolation at the initial and final depth. A TRIME-FM instrument (IMKO, Ettlingen, Germany) was used to obtain the soil moisture (TDR) data.

2.4 Plant analysis and efficiency indices

The dry matter and P content of maize were measured at physiological maturity. Ten plants from each plot were randomly selected to collect, and the entire plants were dried at 60 °C for 3-4 days to obtain a constant weight. Subsamples were collected and ground to pass through a 1 mm sieve. The amount of phosphorus in the leaf tissue was determined by digesting the sample in an acid mixture ($HClO_4$:HNO_3 - 1:5) followed by P analysis on a spectrophotometer using the vanadomolybdo-phosphoric acid yellow colour method (Cottenie, 1980).

Maize roots were sampled at the tasselling stage using an auger with a volume of 475 cm^3. To compose a sample, two subsamples were collected between plants and at 20 cm from each maize row. All of the plots were sampled at depths of 0-10, 10-20 and 20-30 cm, with three samples collected from each plot. The samples were washed with running water in a 2-mm sieve superimposed on a 1-mm sieve to separate the roots from the soil, assuming that only thicker roots would be considered. The maize roots were manually separated from those of other plant species with forceps, and the root length density (RLD) was evaluated using Newman's method of intersections modified by Tennant (1975).

The inorganic phosphorus recovery efficiency was calculated only for the phosphorus applied in 2013, using the following formula: (IPRE) = [(kg/ha P taken up in the treatment – kg/ha P taken up in the control) / kg/ha total of mineral P applied] x 100.

2.5 Statistical analyses

The data were analysed by analysis of variance (ANOVA), and the means were compared by Duncan's post hoc test at a $p = 0.05$ significance level. The data were analysed using InfoStat software (InfoStat Group, College of Agricultural Sciences, National University of Córdoba, Argentina).

3 Results

There was a positive effect of superficial gypsum application on the calcium content in the soil profile up to the 30-40 cm layer, where the calcium was twice more than control in all gypsum treatments (Figure 1). In turn, the plots with gypsum plus leguminous residues showed higher calcium contents than the control in all of the layers up to 40 cm. However, in the 0-10 cm layer, the calcium content was not significantly different among L, UG6 and the control. In the 10-20 cm layer, the order of calcium contents was C = L < UG6 = LG6 < LUG6 < LUG12. This was the only layer in which there was a difference among the treatments with urea, gypsum and leguminous residues, where LUG6 < LUG12. In the 10-30 cm layer, the calcium content was higher in LG6 than in UG6, showing a positive effect of legume application on calcium retention.

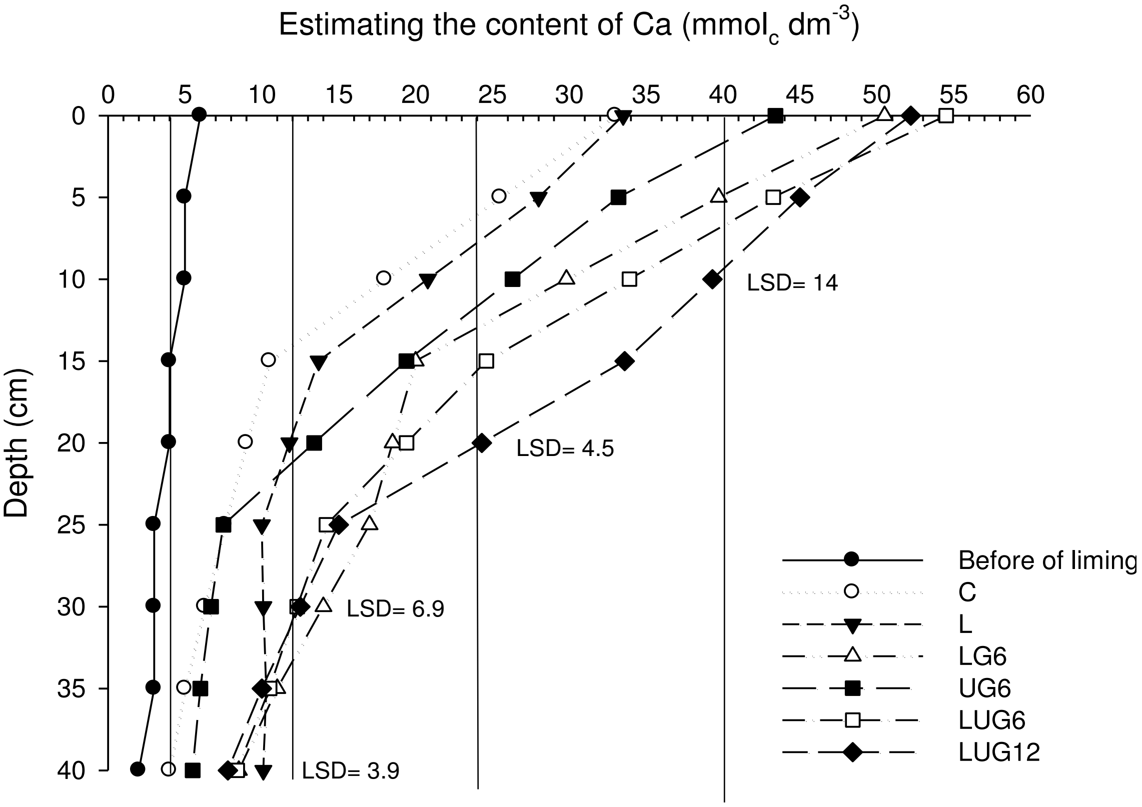

Figure 1: Estimating of the content calcium in the soil in the experimental treatments, in the depth of 0 – 40 cm in 2013. C = without residue and gypsum ; L = 12 Mg/ha of dry matter residue from leguminous; LG6 = 12 Mg/ha of dry matter residue from leguminous and 6 Mg/ha of gypsum; UG6 = 90 kg/ha of N from urea, 6 Mg/ha of gypsum; LUG6 = 90 kg/ha of N from urea, 6 Mg/ha of gypsum and 12 Mg/ha of dry matter residue from leguminous and LUG12 = 90 kg/ha of N from urea, 12 Mg/ha of gypsum and 12 Mg/ha of dry matter residue from leguminous. Different letters in the same row indicate significant difference at the 5% level by Duncan's test.

After three years of gypsum application, the calcium content in profile shows high levels at the 20 cm layer only in the LUG12 treatment. All of the other gypsum treatments had intermediate levels in this layer. In the treatments LG6, LUG6 and LUG12, calcium levels were intermediate at 30 cm. In the control, the calcium contents were intermediate only up to the 10 cm depth. None of the treatments resulted in intermediate calcium levels at the 40 cm depth.

The soil properties affecting soil rootability were more strongly enhanced in the plots where gypsum and leguminous residues were combined with urea (Table 1). Thus, both the LUG6 and LUG12 treatments showed lower soil densities at the 10 cm depth and higher porosities than the control. The other treatments did not show significantly different results. There were no differences among treatments in air capacity or saturated volumetric water contents.

Table 1: Total porosity, soil bulk density, macroporosity, saturated volumetric water content, in the experimental treatments, in the depth of 8–12 cm.

Physical indicators	Control	L	LG6	UG6	LUG6	LUG12
Total porosity (m^3/m^3)	0.44 c	0.44 abc	0.45 abc	0.47 a	0.44 abc	0.46 ab
Soil bulk density (Mg/m^3)	1.52 a	1.47 ab	1.47 ab	1.43 b	1.48 ab	1.42 b
Macroporosity (m^3/m^3)	0.27 a	0.27 a	0.27 a	0.27a	0.28 a	0.28 a
Saturated volumetric water content (m^3/ m^3)	0.41 a	0.40 a	0.42 a	0.41 a	0.42 a	0.42 a
Soil moisture (%)	15.53 a	15.73 a	16.23 a	15.70 a	16.30 a	15.00 a

Control = without residue and gypsum ; L = 12 t/ha of dry matter residue from leguminous; LG6 = 12 t/ha of dry matter residue from leguminous and 6 t/ha of gypsum; UG6 = 90 kg/ha of N from urea, 6 t/ha of gypsum; LUG6 = 90 kg/ha of N from urea, 6 t/ha of gypsum and 12 t/ha of dry matter residue from leguminous and LUG12 = 90 kg/ha of N from urea, 12 t/ha of gypsum and 12 t/ha of dry matter residue from leguminous. Different letters in the same row indicate significant difference at the 5% level by Duncan's test.

In LUG12, the penetration strength was lower than UG6 and L up to the 10 cm depth and was lower than in the control up to the 15 cm layer (Figure 2). In LUG6 also the penetration strength was lower than control in the 0-10 cm layer. In LG6, the penetration strength was lower than control only in the 5-10 cm layer.

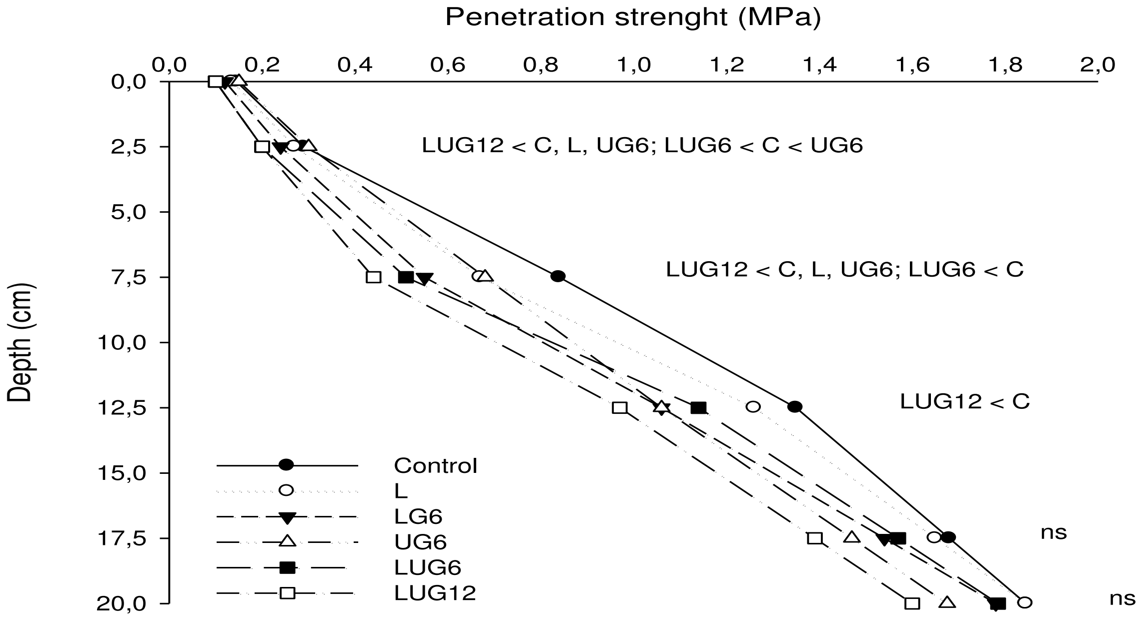

Figure 2: Penetration strength after 7 days without rain. Control = without residue and gypsum; L = 12 Mg/ ha of dry matter residue from leguminous; LG6 = 12 Mg/ha of dry matter residue from leguminous and 6 Mg/ha of gypsum ;UG6 = 90 kg/ha of N from urea, 6 Mg/ha of gypsum; LUG6 = 90 kg/ha of N from urea, 6 Mg/ha of gypsum and 12 Mg/ha of dry matter residue from leguminous and LUG12 = 90 kg/ha of N from urea, 12 Mg/ha of gypsum and 12 Mg/ha of dry matter residue from leguminous. Different letters in the same row indicate significant difference at the 5% level by Duncan's test.

Both leguminous residues and gypsum affected the root growth (Figure 3). Thus, the root length density (RLD) was higher in all treatments than control up to the 20 cm depth. In LUG12, the RLD was also higher than in LG6 and L in the 0-10 cm layer. In the 10-20 cm layer, the order of RLD was as follows: LUG12 > LUG6 > UG6 = GL6 = L > C. It is worth highlighting that at the depth of 20 to 30 cm, the RLD was twice as high in LUG12 than in the control and higher than in the LUG6. In the other treatments, the RLD was not significantly different than control in this layer.

There was also a large and positive effect of the leguminous residues and gypsum on the production of maize dry matter (Figure 3). The use of leguminous residues alone increased the weight of dry matter by 75% relative to the control. The results of the treatments with leucaena, leucaena combined with gypsum or leucaena combined with gypsum and urea (L, LG6, LUG6 and LUG12) were superior to the results of the treatments control and UG6. There was no difference between the LUG6 and LUG12 treatments, whose dry matter was higher than in all other treatments.

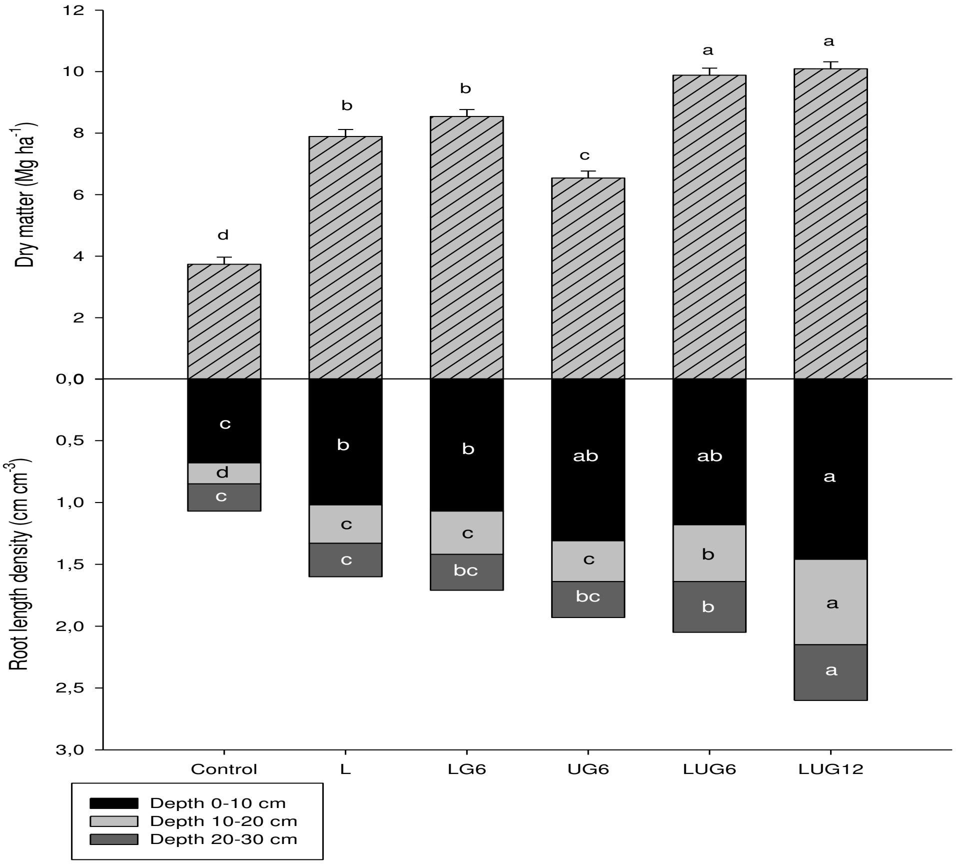

Figure 3: Dry matter of maize at physiological maturity and root length density in the experimental treatments, in the depth of 0 – 30 cm in 2013. Control = without residue and gypsum; L = 12 Mg/ha of dry matter residue from leguminous; LG6 = 12 Mg/ha of dry matter residue from leguminous and 6 Mg/ha of gypsum ;UG6 = 90 kg/ha of N from urea, 6 Mg/ha of gypsum; LUG6 = 90 kg/ha of N from urea, 6 Mg/ha of gypsum and 12 Mg/ha of dry matter residue from leguminous and LUG12 = 90 kg/ha of N from urea, 12 Mg/ ha of gypsum and 12 Mg/ha of dry matter residue from leguminous. Different letters in the same row indicate significant difference at the 5% level by Duncan's test.

The combination of gypsum, leguminous residues and urea had a large effect on the inorganic recovery phosphorus efficiency (IRPE) (Figure 4). Thus, the IRPE in LUG12 was higher than all the other treatments, being six times higher than leguminous. The IRPE in the other treatments with gypsum plus leguminous residues (LG6 and LUG6) was higher than

UG6 and L. In turn, the IRPE in LG6 was four times higher than in UG6, demonstrating the positive effect of the leguminous residues on phosphorus uptake.

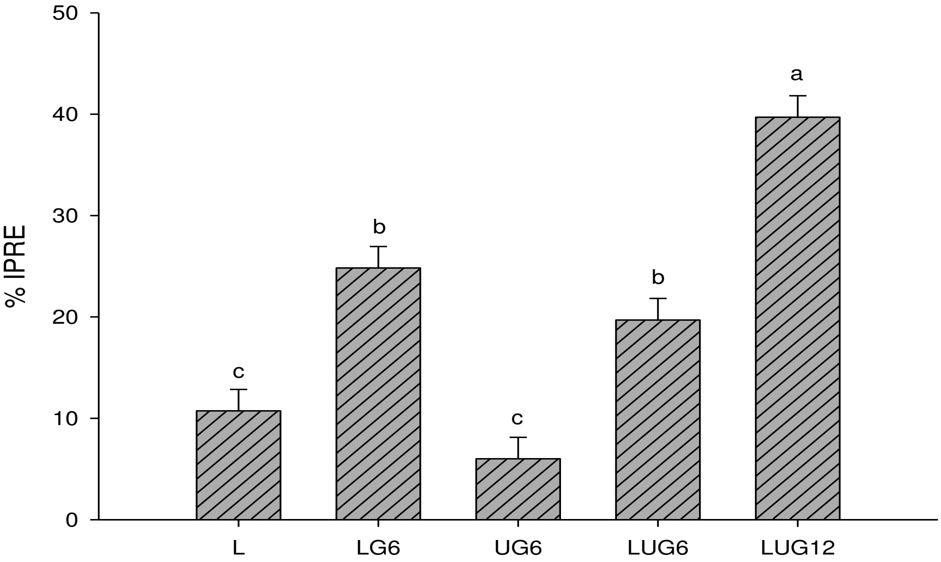

Figure 4: Inorganic phosphorus recovery efficiency (IPRE) in maize. L = 12 Mg/ha of dry matter residue from leguminous; LG6 = 12 Mg/ha of dry matter residue from leguminous and 6 Mg/ha of gypsum ;UG6 = 90 kg/ha of N from urea, 6 Mg/ha of gypsum; LUG6 = 90 kg/ha of N from urea, 6 Mg/ha of gypsum and 12 Mg/ha of dry matter residue from leguminous and LUG12 = 90 kg/ha of N from urea, 12 Mg/ha of gypsum and 12 Mg/ha of dry matter residue from leguminous. Different letters in the same row indicate significant difference at the 5% level by Duncan's test.

4 Discussion

Our results confirm that the superficial application of gypsum efficiently increases the calcium content in soil profile in the humid tropics. In addition to the solubility of gypsum, the high rainfall levels of the period (4,700 mm) and high water infiltration rates of the local soil (Moura *et al.*, 2009) can account for the downward movement of gypsum in the soil profile. However, in soil without organic residues, the calcium content was affected more by the liming than the gypsum application. In the UG6 treatment, the calcium content was higher than without gypsum only below 30 cm. The higher calcium contents in the soil profiles with leguminous residues must be attributed to the higher levels of organic matter derived from the decomposition of the residues applied during the three experimental years (data not shown). In the same soil with leguminous residues, Moura *et al.* (2012) found higher organic matter levels and calcium contents after lime application relative to bare soil.

According to Caravaca & Albaladejo (1999), the cation retention capacity of whole soils is closely correlated with their respective C contents. This pattern can account for the differences in calcium contents (more than 50%) between LG6 and UG6 in the 10-30 cm layer. In turn, the small differences in calcium contents between the treatments LUG12 and LUG6 suggest no direct correlation between gypsum applied and calcium contents to the depth of 40 cm. In most sandy soils with small buffering capacity in which Ca^{++} ions do not interact strongly with the soil matrix, the application of Ca fertilisers results in a higher Ca^{++} concentration in the solution, which can then be leached out of root zone (Kolahchi & Jalali, 2007).

The differences in physical indicators between LUG12 and LUG6 relative to the control, UG6 and L showed that the combination of leguminous residues and gypsum can more efficiently improve the soil rootability than the isolated use of gypsum or leguminous residues alone. In turn, because there were no differences in the soil moisture, the variation in penetration strength can be explained by the management practices used. Moura *et al.* (2012) found effects of leguminous residues on penetration strength only up to the 5-10 cm layer, even after seven years of residue application, suggesting a positive effect of gypsum in the lower layers during this experiment.

Although both the residues and gypsum increased the root density in the profile up to 30 cm, it is worth highlighting that the root growth in the control was minimal below 10 cm. According to Ley *et al.* (1995), effects on root growth in soil that tends to harden are common when the water potential approaches -100 kPa, a level that, according to Moura *et al.* (2009), occurs in this experiment after four days without rainfall.

The higher root growth up to the 20 cm depth relative to the control can be accounted for by the improvement in soil rootability caused by leguminous residue and gypsum given that in L and in UG6, the RLD was also higher than in the control. According to Shepherd et al. (2002), residue application may contribute to an favourable environment to root growth by increasing the free light fraction of organic matter, that promotes the formation of "ephemeral structure" in structurally fragile soil. In turn, in the 20-30 cm layer, the RLD in LUG12 was twice the control (22 to 45 cm cm^{-3}), which also can be attributed to the effect of the calcium on the reduction of the strength of the soil in this layer (Sumner, 2009).

According to Sumner *et al.* (1990), the improvements caused by gypsum for plants are both direct (influencing the flocculation and aggregation of subsoil) and indirect (improving root activity, leading to a greater soil aggregation). The RLD was not different between LG6 and UG6, which suggests that the results of urea and leguminous residue were equivalent when accompanied by gypsum. However, in the 10-20 cm layer, the RLD was larger in LUG6 than in LG6, which shows the positive effect of urea on the root growth when combined with gypsum and residues. According to Guo *et al.* (2005), a local supply of nitrate can significantly increase lateral root elongation. Moura *et al.* (2013) reported that in soil covered with leguminous residues in similar conditions used in the present experiment, nitrogen use efficiency is higher.

The dry matter production shows the agronomic importance of gypsum and leguminous residue for crop growth under the conditions of this experiment. While the increase in dry matter due leguminous residues alone was 75% compared to the control, the application of gypsum led to an additional increase of 20% when compared to the L (6,5 t/ha) and LG6 (7,8 t/ha) treatments. The effect of soil cover with leguminous residues on maize growth in this soil was reported by Moura *et al.* (2009) and can be attributed mainly to the higher plant transpiration rate in covered soil and therefore the higher CO_2 assimilation and higher nutrient uptake. Both processes rely heavily on increased root length and density through mulching. The effects of gypsum can be explained in the same way in this experiment.

The combination of gypsum and residues increased the efficiency of phosphorus recovery dramatically compared to the application of one of these amendments alone. Given the low mobility of phosphorus in soil, the ability of a plant to take up phosphorus is largely due to its root distribution relative to the location of phosphorus in the root zone. Thus, the uptake of phosphorus from each layer of soil was related to the length of the roots in that layer (Shierlaw & Alston, 1984). The positive effects of residue application on the increase in P usage efficiency in no-tillage systems may also be due to decreased P sorption, promoting competition between residue decomposition products and P at sorption sites (Gupy *et al.*, 2005), or to the production of organic acids and humic substances during decomposition, which are also involved in the P solubilisation process (Singh & Amberger, 1990). It is worth highlighting that the larger RLD in LUG12 resulted in a major phosphorus uptake, even with high calcium contents, which suggests that there were no negative effects of this high calcium availability on P sorption.

5 Conclusions

The application of gypsum plus leguminous residues can enhance the soil rootability when used in tropical soil prone to cohesion, due to the combined effects of increased porosity and decreased penetration strength. These effects are like longer root growth into deeper soil layers and higher phosphorus uptake. The leguminous of residue favours an input and retention of calcium derived from the gypsum in deeper layers. However, the use of large amounts of gypsum (such as 12 t/ha) with residue, though strongly increasing the phosphorus uptake by maize, do not promote a proportional increase in maize dry matter production. In addition, given the small differences in calcium contents between the treatments with 6 and 12 t/ha, split the application of gypsum in combination with residue applications, rather than a single high dose, is recommended for tropical sandy loam soils with low cation retention capacities.

Acknowledgements

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References

Aguiar, A.C.F., Bicudo, S.J., Costa Sobrinho J.R.S., Martins A.L.S., Coelho K.P. & Moura E.G. 2010. Nutrient recycling and physical indicators of an alley cropping system in a sandy loam soil in the Pre- Amazon region of Brazil. *Nutrient Cycling in Agroecosystems.* **86**, 189–198.

Aguiar, A.C.F., Freitas, I.C., Carvalho, C.S., Monroe, P.H.M & Moura, E.G. 2011. Efficiency of an agrosystem designed for family farming in pre-Amazon region. *Renewable Agriculture and Food Systems*, **26**, 24-30.

Aikins, S.H.M. & Afuakwa, J.J. 2012. Effect of four different tillage practices on soil physical properties under cowpea. *Agriculture and Biology Journal of North America*, **3**, 17-24.

Brady, N.C & Weil, R.R. 1996. The Nature and Properties of Soils. 11th Edn., *Macmillan Publishing Company.*, New York, USA., pp: 351-367.

Becher, H.H., Breuer, J. & Klingler, B. 1997. An index value for characterizing hardsetting soils by fall-cone penetration. *Soil Technology*, **10**, 47–56.

Blanco-Canqui, H & Lal, R. 2007. Soil and crop response to harvesting corn residues for biofuel production. Geoderma, **141**, 355-362.

Caravaca, F., Lax, A & Albaladejo, J. 1999. Organic matter, nutrient contents and cation exchange capacity in fine fractions from semiarid calcareous soils *Geoderma* **93**, 161–176.

Celentano, D., Rousseau, G.X., EngeL,V., Façanha, C.L., Oliveira, E.M. & Moura, E.G 2014. Perceptions of environmental change and use of traditional knowledge to plan riparian forest restoration with relocated communities in Alcantara, Eastern Amazon. Journal of Ethnobiology and Ethnomedicine, **10**, 11.

Cottenie, A. 1980. Soil and plant testing as a basis of fertilizer recommendations. FAO *Soil Bulletin 38/2, FAO* Rome, Italy.

Dechert, G., Veldkamp E. & Brumme R., 2005. Are partial nutrient balances suitable to evaluate nutrient sustainability of land use systems? Results from a case study in Central Sulawesi, Indonesia. *Nutrient Cycling in Agroecosystems*, **72**, 201–212.

Guppy, C.N., Menzies, N.W., Moody, P.W. & Blamey, F.P.C. 2005. Competitive sorption reactions between phosphorus and organic matter in soil: A review. *Australian Journal of Soil Research*, **43**, 189-202.

Guo Y., Mi G.H., Chen F & Zhang F. 2005. Effect of NO3 Supply on Later Root Growth in Maize Plants, *Journal of Plant Physiology and Molecular Biology,* **31**, 90-96.

Kordlaghari, M.P. & Rowell, D.L. 2006. The role of gypsum in the reactions of phosphate with soils. *Geoderma,* **32**, 105–115.

Kolahchi, Z & Jalali, M. 2007. Effect of water quality on theleaching of potassium from sandy soil. *Journal of Arid Environments*, **68**, 624-639.

Ley, G.J., Mullins, C.E. & Lal, R. 1995. The potential restriction to root growth in structurally weak tropical soils. *Soil & Tillage Research*, **33**, 133–142.

Moura, E.G., Moura, N.G., Marques, E.S., Pinheiro, K.M., Costa Sobrinho, J.R.S & Aguiar, A.C.F. 2009. Evaluating chemical and physical quality indicators for a structurally fragile tropical soil. *Soil and Use Management*, **25**, 368-375.

Moura, E.G., Oliveira, A.K.C., Pinheiro, K.M & Aguiar, A.C.F. 2012. Management of a cohesive tropical soil enhance rootability and increase the efficiency of nitrogen and potassium use. *Soil Use and Management*, **28**, 370-377.

Moura, E.G., Sena, V.G.L., Correa, M.S., Aguiar, A.F.C. 2013. The Importance of an Alternative for Sustainability of Agriculture around the Periphery of the Amazon. Rainforest. *Recent Patents on Food, Nutrition & Agriculture*, **5**, 70-78.

Mullins, C.E., 1999. Hardsetting soils, In: *Handbook of soil science* (ed. M. E. Summer), CRC Press, New York, pp. G65-G87.

Radcliffe, D. E., Clark, R. L & Sumner, M. E., 1986. Effect of gypsum and deep-rooting perennials on subsoil mechanical impedance. *Soil Science Society America Journal*, **50**, 1566-1570.

Raij, B., Quaggio, J.A. & Silva N.M., 1986. Extraction of phosphorus, potassium, calcium, and magnesium from soils by an ion-exchange resin procedure. *Communications in Soil Science and Plant Analysis*, **17**, 547-566.

Ribeiro, A.C., Guimarães, P.T.G & Alvarez, V.H.V. 1999. Recomendações para o uso de corretivos e fertilizantes em Minas Gerais-5ª Aproximação. Viçosa, Minas Gerais.

Sumner, M.E., Radcliffe, D.E., McCray, M.,Carter, E & Clark, R.L. 1990. Gypsum as an ameliorant for subsoil hardpans. *Soil Technology*, **3**, 253-258.

Sumner, M.E 2009. Gypsum improves subsoil root growth. Proceedings of International symposium "Root Reseacher and Aplications, sept, 2-4, BOKU,Viena, Austria,1-4.

Silva, A.P. & Kay, B.D. 1997. Estimating the least limiting water range of soils from properties and management. *Soil Science Society of American Journal*, **61**, 877–883.

Singh C.P & Amberger A. 1990. Humic substances in straw compost with rock phosphate. *Biological Wastes*, **31**, 165–174.

Shierlaw,J & Aston, A.M.1984. Effect of soil compaction on root growth and uptake of phosphorus - *Plant and Soil*, **77**, 15-28.

Shepherd, M.A., Harrison, R & Webb, J. 2002. Managing soil organic matter-implications for structure on organic farms. Soil Use and Management, **18**, 284-292.

Tennant, D. 1975. A test of a modified line intersect method of estimating root length. *Journal of Ecology*, **63**, 995–1001.

Thomasson, A.J. 1978. Towards an objective classification of soil structure. *Journal of Soil Science*, **29**, 38–46.

Vance, C.P., Unde-Stone, C & Allan, D.L. 2003. Phosphorus acquisition and use: critical adaptation by plants for securing a nonrenewable resource. *New Phytologist*, **157**, 423-447.

ANEXO

Soil Use and Management

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