

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

**STÉFANNY BARROS PORTELA**

**USO DE GESSO E RESÍDUOS DE LEGUMINOSAS PARA  
MELHORAR A ENRAIZABILIDADE DE UM SOLO TROPICAL COESO  
E AUMENTAR A PRODUTIVIDADE DO MILHO**

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. Emanuel Gomes de Moura**

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São Luís

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**DEDICO**

A Deus, que é o provedor de tudo.

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Aos meus irmãos pelo apoio e confiança.

Ao meu namorado pelo carinho e companheirismo.

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*“Tudo posso naquele que me fortalece.”*

***Filipenses 4, 13.***



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**CAPÍTULO I**

## 1. INTRODUÇÃO GERAL

Na região do trópico úmido, a maioria dos solos apresenta baixa fertilidade natural por serem derivados de rochas sedimentares clásticas (AGUIAR *et al.*, 2010). Sua mineralogia de argila é frequentemente dominada por caulinita e na maioria das vezes são pobres em matéria orgânica (MOURA *et al.*, 2008). Essas características são comuns em solos propensos à coesão e que geralmente estão sob condições climáticas de períodos secos e úmidos alternados (CHARTRES *et al.*, 1990). Normalmente, esses solos endurecem significativamente, quando secos, dificultando ou mesmo impossibilitando o preparo para o cultivo, e cessam tal impedimento, no momento em que são umedecidos (MULLINS, 1999). Essa alta propensão à coesão dificulta a enraizabilidade das plantas e diminui a eficiência do uso da água e dos nutrientes (LEY *et al.*, 1995).

Nessa região são observados padrões muito baixos, no que tange à medida mais tradicional de produtividade agrícola - a produção por hectare. Estudos experimentais com o objetivo de aumentar a eficiência do uso de nutrientes na região do trópico úmido, desenvolvidos por Moura *et al.* (2016) e Aguiar *et al.* (2010), obtiveram diferenças de 60% e 52,5% no rendimento do milho de sequeiro nos períodos de 2011-2013 e 2003-2006, respectivamente.

Práticas agrícolas que são recomendadas para o cerrado brasileiro - como saturação do solo com fertilizantes solúveis, aração e gradagem - não garantem a sustentabilidade dos agroecossistemas nessa região por não se adequarem às características edafoclimáticas locais (MOURA *et al.*, 2013). A combinação de temperaturas elevadas com alta pluviosidade sazonal aumenta a perda dos fertilizantes solúveis, particularmente dos que apresentam elevada mobilidade no perfil do solo, como o nitrogênio e o potássio. Além disso, os solos tropicais possuem baixa disponibilidade e uma alta capacidade de fixação de fósforo, o que muitas vezes limita o crescimento e a produção das culturas (VANCE *et al.*, 2003).

Estratégias para aumentar a eficiência do uso de nutrientes em solos coesos do trópico úmido devem 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 (LAL, 2009). De tal modo, práticas consideradas sustentáveis - como o plantio direto, a aplicação de compostagem e biomassa, uso de

biofertilizantes, sistemas agroflorestais e cobertura superficial do solo com leguminosas - podem ser utilizadas na tentativa de aumento de produtividade.

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). Ademais, a adição de resíduos de plantas como cobertura do solo também diminui a resistência à penetração e aumenta o conteúdo de água no solo por conservar a umidade e reduzir 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 arbóreas de alta qualidade com outra de baixa qualidade 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. As vantagens mais importantes deste sistema são: aumento da capacidade de aeração do solo, a moderação nos valores de nitrogênio (N) adicional e o aumento dos níveis de cálcio (Ca) na zona radicular (AGUIAR *et al.*, 2010).

Outro fator interessante é que essa prática aumenta os estoques de carbono orgânico do solo e os teores de agregados estáveis em água (SAROA e LAL, 2003; OBADE e LAL, 2014). Segundo Chaney e Swift (1984), existe alta correlação entre estabilidade de agregados e a matéria orgânica do solo. Isto também pode ser atribuído ao aumento da atividade fúngica e bacteriana. No entanto, melhorias nas propriedades estruturais do solo com resíduos vegetais são significativas apenas superficialmente (BLANCO CANQUI e LAL, 2007). Adicionalmente, Wong e Asseng (2007) e Cook *et al.* (2006) observaram que os efeitos diretos dos resíduos nos atributos do solo não se estendem para além de 10 cm abaixo da superfície, o que não é suficiente para produzir o crescimento da raiz e para aumentar a eficiência do uso de nutrientes adequadamente.

Para ampliar a espessura da camada enraizável, alguns autores recomendam o uso de cálcio como um agente "floculante", pois melhora a estrutura do solo por

reduzir a dispersão da argila (RADCLIFFE *et al.*, 1986; OSTER *et al.*, 1999; MOURA *et al.*, 2016). Assim, a aplicação de gesso ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) no solo, aumenta a disponibilidade de  $\text{Ca}^{2+}$ , o que pode aumentar a atividade da raiz em camadas mais profundas, melhorar a estabilidade dos agregados e, conseqüentemente, aumentar a eficiência da absorção de água e nutrientes (SUMNER *et al.*, 1990; CAIRES *et al.*, 2011).

Outra característica relevante é que o gesso tem a capacidade de liberação de eletrólitos que aumentam a agregação das frações orgânicas do solo (FLANAGAN *et al.*, 1997; NORTON e DONTSOVA, 1998; VÁZQUEZ *et al.*, 2009). O fornecimento de Ca em solos ligeiramente lixiviados é importante para a proteção da biomassa e outros materiais orgânicos de mineralização rápida (OADES, 1988; WHITTINGHILL e HOBBIE, 2012).

Dessa forma, as interações entre a elevada evaporação atmosférica, a baixa disponibilidade de nutrientes e a redução da espessura da camada enraizável, podem reduzir o crescimento das culturas e tornar os agrossistemas inviáveis. Assim, aumentar o volume de solo explorado pelas raízes das culturas é crucial para eficiência do uso da água e dos nutrientes na viabilidade dos sistemas de culturas na região do trópico úmido. Portanto, este trabalho visa avaliar a combinação dos efeitos do gesso com biomassa de leguminosas arbóreas nos níveis de cálcio e carbono orgânico do solo na zona radicular e como isso pode afetar a resistência a penetração do solo, absorção de nitrogênio e o rendimento do milho em um solo arenoso propenso à coesão.

## 2. REFERENCIAL TEÓRICO

### 2.1 Intensificação Ecológica da Agricultura (IEA)

A intensificação da agricultura é conduzida pela combinação de três tendências globais: o crescimento da população; a mudança no hábito alimentar de países populosos, tais como, China e Índia; e as pressões sobre a área agricultável devido à concorrência com a urbanização e com a produção de fibras e combustíveis (HOCHMAN *et al.*, 2011). Anteriormente, a intensificação era baseada na implementação de irrigação, cultivo intensivo, mecanização e aplicação de mais fertilizantes, corretivos e pesticidas (MATSON *et al.*, 1997; CASSMAN, 1999).

Essas medidas aumentaram drasticamente a produção de alimentos em todo o mundo, no entanto, muitas pessoas permanecem com fome (PINGALI, 2012). Segundo o último relatório da FAO (2015), cerca de 795 milhões de pessoas estão subnutridas no mundo. Além disso, a intensificação resultou em amplas consequências ambientais negativas (TILMAN *et al.*, 2002; GODFRAY *et al.*, 2010).

O crescimento da população global deverá atingir 9,2 bilhões de pessoas (7,9-10,4 bilhões) até 2050 (ONU, 2009; NELSON *et al.*, 2010), o que representa um grande desafio para a agricultura, visto que é necessário alimentar o mundo, protegendo os recursos naturais e os serviços ambientais. Dessa forma, a intensificação ecológica da agricultura (IEA) ganhou atenção nas atuais discussões políticas, pois tem como objetivo, não só a maximização da produção de alimentos por área, mas interesse simultâneo na segurança alimentar e ambiental (GODFRAY *et al.*, 2010).

Além disso, a IEA fundamenta-se na redução da dependência de recursos não renováveis com o intuito de manter a fertilidade do solo e a biodiversidade e, assim, minimizar as consequências externas ao local da agricultura, tais como a erosão do solo, a poluição das águas subterrâneas, a eutrofização dos rios e lagos e a redução das emissões de gases do efeito estufa. A abordagem da IEA tem sido proposta como o principal meio para alimentar uma população em crescimento (GODFRAY *et al.*, 2010), ainda que especificidades dos tipos de desenvolvimento e transferências de tecnologias tenham sido insuficientes e distantes entre si em



chamadas recentes para sua expansão global (TILMAN *et al.*, 2011; BEDDINGTON *et al.*, 2012).

A primeira lei da termodinâmica, uma lei empírica da física, afirma que a energia dentro de um sistema isolado não pode ser criada nem destruída, só pode mudar de forma. Na agricultura, como na natureza, a energia solar é transformada em alimentos. Essa transformação exige entradas, como água e nutrientes que são acessados a partir do solo. No entanto, a agricultura não é um sistema fechado; recursos adicionais, tais como o trabalho e o capital são necessários para alterar um sistema natural para um sistema de gestão agrícola (BEDDINGTON *et al.*, 2012).

Quando o alimento ou fibra deixa o sistema agrícola, ou este se torna empobrecido, ou recursos de fora do sistema de produção agrícola são obrigados a manter um equilíbrio de entrada para garantir um sistema de produção equilibrado e sustentável. Apesar de que alguns insumos podem ser reciclados a partir de alimentos ou adquiridos a partir da atmosfera (por exemplo, fixação de N<sub>2</sub>), a agricultura é, em última instância, dependente de insumos externos e na medida em que essas entradas não são renováveis, há um limite para a sustentabilidade da agricultura (HOCHMAN e CARBERRY, 2011).

Conceitos de agricultura eco-eficiente foram revisados por Keating *et al.* (2010) que descreveram a eco-eficiência como multidimensional e influenciada por múltiplos fatores que interagem de forma não linear. De Wit (1992) ressalta que, embora a resposta a qualquer entrada (por exemplo, fertilizantes nitrogenados) está sujeita à lei dos acréscimos decrescentes, "... a maioria dos recursos de produção são utilizados de forma mais eficiente com o aumento do acréscimo, devido à maior otimização das condições de crescimento".

Embora não haja um limite para a quantidade de recursos escassos ou não renováveis que podem ser usados, é, pelo menos, teoricamente possível intensificar simultaneamente a produção e utilização de recursos. Assim, o conceito IEA depende da identificação e redução do uso ineficiente de recursos, para manter a fertilidade do solo e a biodiversidade, e reduzir as consequências ambientais externas ao local de agricultura (HOCHMAN *et al.*, 2011).

Dessa forma, as políticas públicas devem fornecer incentivos para a adoção de práticas agrícolas sustentáveis - gestão sustentável da terra, conservação do

solo, melhoria da gestão da água, sistemas agrícolas diversificados e sistemas agroflorestais - a fim de produzir maior diversidade de produtos na mesma área e, ao mesmo tempo, reduzir os impactos ambientais negativos (FAO, 2015). Portanto, é necessário o estabelecimento e manutenção de tecnologias que melhoram o rendimento da produção convencional, tais como o uso dos serviços ecossistêmicos, maior aproveitamento dos resíduos vegetais e industriais, ofertar variedades de sementes melhoradas e fertilizantes minerais. Trata-se, pois, de opções valiosas, principalmente quando combinadas com uma maior atenção para a utilização desses insumos de forma eficiente.

## **2.2 Disponibilidade e eficiência do uso de N**

Melhorar a eficiência do uso de nutrientes é um pré-requisito essencial para a 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, 1984; CENTRE, 2014).

A absorção de nutrientes pelas plantas está fortemente relacionada com a produção de biomassa vegetal. Consequentemente, aumentar a produtividade das culturas requer maior absorção de nutrientes (CASSMAN *et al.*, 2003). Esta relação é especialmente verdadeira para o nitrogênio (N), pois é o nutriente requerido em maior quantidade pelas plantas (GREENWOOD *et al.*, 1990). No entanto, há alta taxa de remoção de N no perfil do solo, devido às perdas por lixiviação e desnitrificação que provocam impacto negativo sobre a qualidade da água e emissões de gases de efeito estufa (GALLOWAY e COWLING, 2002).

Neste contexto, para aumentar o rendimento de grãos, é indispensável reduzir a ineficiência de N (CASSMAN *et al.*, 2003). Na verdade, a média alcançada na eficiência do uso de N sintético pelos agricultores é bastante baixa em sistemas de produção de alto rendimento: 31% para o arroz irrigado na Ásia, 18-49% para o trigo irrigado em sistemas de arroz-trigo na Índia e 37% para o milho de sequeiro nos Estados Unidos (CASSMAN *et al.*, 2002). Por outro lado, a fixação biológica de nitrogênio atmosférico por organismos procariontes contribui com cerca de 90% dos

processos naturais de fixação e é superior em 70% à fixação industrial (TAIZ e ZEIGER, 2013).

Para reduzir as perdas de N sintético no solo, pesquisadores recomendam técnicas baseadas na melhoria da congruência entre a demanda imediata de N da cultura e a oferta imediata de N do solo (DOBERMANN e CASSMAN, 2002). Essa medida evita a aplicação em excesso de N inorgânico no sistema do solo e mensura a demanda de N da cultura em curto prazo, o que diminui as perdas por lixiviação, desnitrificação, volatilização, ou escoamento.

O rendimento da cultura e a eficiência do uso de N sob condições de campo podem ser melhoradas por meio de tecnologias, tais como: múltiplas aplicações parceladas; detecção em tempo real do status de N na planta com um medidor de clorofila para orientar a época de aplicação de N; e gestão na escolha do fertilizante nitrogenado ou gestão na escolha do N orgânico disponível no local (PENG *et al.*, 1996; DOBERMANN *et al.*, 2002).

A escolha do fertilizante nitrogenado depende do número de parcelamentos das aplicações. Bauder e Montgomery (1980) avaliaram a lixiviação derivada de três fontes de N e concluíram que as perdas obedeceram à seguinte sequência: uréia < sulfato de amônia < nitrato de cálcio. A liberação controlada de fertilizantes também melhora a eficiência do uso de nutrientes, aumentando a congruência entre a oferta de N do solo sob a demanda da cultura (SHOJI e KANNO, 1994).

Vários autores relataram que o baixo teor de matéria orgânica no solo, aumentou acentuadamente a deficiência de N nas culturas (SAINZ ROZAS *et al.*, 2008; VELASCO *et al.*, 2012; BARBIERI *et al.*, 2015). Dessa forma, a quantidade de N recomendada ganhou acréscimos que contribuíram para a progressiva acidificação do solo, o que diminuiu a disponibilidade de nutrientes afetando o crescimento das plantas (BRADY e WEILL, 1999; SAINZ ROZAS *et al.*, 2011). Em curto prazo, a acidez do solo se desenvolve principalmente devido à remoção de bases (por exemplo, Ca, Mg, K,) por exportação das culturas (BOUMAN *et al.*, 1995), acoplado com o ácido residual, que é deixado no solo a partir de adubação com N e P (TARKALSON *et al.*, 2006).

Aumentar a dosagem de fertilizante aplicado ao solo, além do alto custo, não garante maior rendimento de grãos. Dessa forma, a absorção de N na zona radicular

pode ser melhorada quando os fertilizantes são adicionados nas formas de liberação mais lenta ou quando disponibilizados por processos biologicamente mediados, a exemplo do caso da adubação verde (DRINKWATER e SNAPP, 2007; AGUIAR *et al.*, 2010). De tal modo, práticas consideradas sustentáveis - como o plantio direto, a aplicação de compostagem e biomassa, uso de biossólidos, sistemas agroflorestais e cobertura superficial com leguminosas - podem aumentar a disponibilidade de N para as plantas e assim aumentar a sua eficiência do uso (LAL, 2009; MOURA *et al.*, 2012).

### **2.3 Melhoria da enraizabilidade em solos coesos**

Um solo com boa qualidade física deve ser firme o suficiente para manter a sua estrutura e evitar o tombamento das plantas, mas também permeável o suficiente para permitir ampla penetração das raízes das plantas e da fauna do solo (TOPP *et al.*, 1997). Estabelecer boa qualidade física do solo para a produção máxima da cultura e saúde do ecossistema envolve a otimização cuidadosa de todas as principais propriedades dos seus atributos físicos (TOPP *et al.*, 1997), especialmente, quando se cultiva em solos propensos à coesão.

Em sua maioria, tais solos são caracterizados por indicarem uma gama de problemas agronômicos, incluindo o tempo restrito para o seu preparo e principalmente os impedimentos físicos para o adequado desenvolvimento radicular (MULLINS *et al.*, 1990). Em termos de distribuição mundial, os solos coesos ocorrem nas regiões tropicais áridas, semi-áridas e mediterrâneas (MULLINS, 1999). Trata-se de uma característica comum em solos sob condições climáticas de períodos secos e úmidos alternados (CHARTRES *et al.*, 1990).

Esse atributo caracteriza solos com horizontes compactados, duros, de condição aparentemente apedal formada durante o secamento, mas que se abranda durante o umedecimento (MCDONALD *et al.*, 1990). Sua mineralogia de argila é frequentemente dominada por caulinita e ilita, e muitas vezes são ricos em sódio trocável e pobre em matéria orgânica (MULLINS *et al.*, 1990). Esses horizontes se endurecem significativamente, quando secos, dificultando ou mesmo impossibilitando o preparo para o cultivo, e cessam esse impedimento no momento

em que são umedecidos, o que pode acontecer depois de uma irrigação por inundação ou de um evento simples como uma chuva intensa (MULLINS, 1999).

A elevada resistência desses solos, quando secos, traz sérias implicações ao crescimento das raízes, porque a resistência do solo à penetração (RP) normalmente excede os 3 MPa, antes que o solo tenha atingido o ponto de murcha permanente (- 1,5 MPa de potencial mátrico). O valor de 3 MPa é suficiente para impedir severamente o crescimento radicular e limitar a emergência de hipocótilos (WEAICH *et al.*, 1992).

Para o crescimento das raízes, o aumento da resistência é particularmente importante durante o secamento dos solos coesos. Nessa situação as raízes não encontram caminhos para se desenvolverem, haja vista a ausência de fendas estruturais. Ley *et al.* (1995) encontraram uma RP igual ou maior a 2 MPa em alguns solos da Nigéria, quando foram secados a um potencial matricial de apenas -0,1 MPa. Resultados similares foram obtidos para solos coesos do Reino Unido, Austrália, Tanzânia, e Brasil (MULLINS *et al.*, 1990; YOUNG *et al.*, 1991; MULLINS *et al.*, 1992; MULLINS, 1997 ).

Nesse contexto, estratégias que aumentam o volume de solo hábil ao desenvolvimento radicular são particularmente interessantes. Exemplo disto é o sistema de plantio direto, pois forma uma camada de resíduo que protege e absorve o impacto da água no solo, reduz a evaporação a partir da superfície, e atrasa a coesão (BECHER *et al.*, 1997; DAHIYA *et al.*, 2007). Além disso, essa prática pode melhorar os indicadores físicos da qualidade do solo, tais como a densidade, a porosidade total e capacidade de aeração (GLINSKI e STEPNIEWSKI, 1986). Outro papel fundamental desse sistema é a ciclagem de nutrientes provenientes da matéria orgânica, capaz de aumentar a retenção de cátions em solos ácidos altamente intemperizados, em que minerais de argila 2:1, que possuem carga permanente, não estão presentes (COLEMAN *et al.*, 1992).

No entanto, melhorias nas propriedades estruturais do solo com a aplicação de resíduos vegetais são somente significativas próximas à superfície do solo (BLANCO CANQUI e LAL, 2007). Isto parece ser especialmente verdadeiro em solos mal drenados, com alta pluviosidade sazonal (RUSINAMHODZI *et al.*, 2011). Moura *et al.* (2013) observaram que os efeitos diretos de resíduos nos atributos do solo não

se estendiam para além de 10 cm abaixo da superfície, o que não é suficiente para produzir o crescimento da raiz e assim aumentar a eficiência do uso da água e dos nutrientes.

Alguns autores recomendam aplicação de gesso para reduzir a dispersão de argila e melhorar a enraizabilidade do solo em maiores profundidades (RADCLIFFE *et al.*, 1986; MOUTIER *et al.*, 1998; OSTER *et al.*, 1999). Essa prática também diminui a capacidade de argila dispersa para endurecer o solo ou aumentar sua resistência (SUMNER, 1995). Isto porque solos com alta concentração de cálcio têm maiores forças atrativas que mantêm microagregados de argila estáveis. Como consequência, o solo adquire melhor estrutura, maiores taxas de infiltração de água e drenagem (MOUTIER *et al.*, 1998; DONTSOVA e NORTON, 2002).

Além disso, o gesso tem a capacidade de liberação de eletrólitos que aumentam a agregação das partículas de argila do solo e das frações orgânicas do solo (BRADY e WEIL, 1996; FLANAGAN *et al.*, 1997; VÁZQUEZ *et al.*, 2009). Alguns autores relataram que a remoção de Ca do solo estimula a decomposição da matéria orgânica e a mineralização do N e, por outro lado, que a adição de Ca inibe a liberação de CO<sub>2</sub> e estabiliza a estrutura do solo (GAIFFE *et al.*, 1984; OADES, 1988).

Zhang e Hartge (1995) relatam que a aplicação de gesso aumentou a densidade do solo devido a um aumento da agregação deste com os ciclos de umedecimento e secagem, e observaram que a resistência à penetração diminuiu. Eles especularam que a estabilidade estrutural do solo foi influenciada pelo teor de água. O conteúdo de água diminuiu à medida que aumentou o número dos ciclos de drenagem, o que pode ser devido à redução da capacidade de retenção de água do solo que recebeu aplicação de gesso.

No entanto, o gesso aplicado na superfície do solo aumenta a concentração de eletrólitos da água da chuva infiltrante (NORTON e ZHANG, 1998), comprime a dupla camada elétrica e fornece Ca<sup>2+</sup> para o complexo de troca onde Mg<sup>2+</sup>, K<sup>+</sup> e o Na<sup>+</sup> também residem (FAVARETTO, 2002; TIRADO-CORBALA *et al.*, 2013). O grau de efeito do eletrólito e a troca irão depender das propriedades do solo (SHAINBERG *et al.*, 1989). Além disso, a redistribuição dos nutrientes para as

diferentes partes do perfil do solo dependerá da condutividade hidráulica e do volume de água que lixivia no solo (TIRADO-CORBALA *et al.*, 2013).

Portanto, em solos de textura grossa, aplicações de gesso combinado ao plantio direto poderiam aumentar significativamente a aeração do solo e a drenagem interna e, desta maneira, criar condições de melhora para o desempenho das culturas. Ademais, um fornecimento de Ca em solos ligeiramente lixiviados é importante para a proteção da biomassa e outros materiais orgânicos de mineralização rápida (OADES, 1988; WHITTINGHILL e HOBBIE, 2012).

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**Use of gypsum and leguminous residue to improve rootability of cohesive tropical soil and increase yield maize**

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**CAPÍTULO II**

Artigo escrito de acordo com as normas da revista Soil & Tillage Research.

## **Use of gypsum and leguminous residue to improve rootability of cohesive tropical soil and increase maize yield**

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### **Abstract**

In cohesive soils of tropical region crops could be able exploit just a thin layer and rooting depth-affected since some subsurface constraints can be a limiting factor to crop yield. We hypothesised that the use of gypsum combined with leguminous residue may extend the thickness of rootable layer, the growth and the maize yield. The aim of this work was to evaluate the combined effects of gypsum and leguminous residue on plant rootability in the soil root zone and on maize yield in a sandy loam cohesive soil. The experiment was initiated in January 2011, following a randomized block design with four replications of the following treatments: control, C - no residue or gypsum; L - 12 Mg ha<sup>-1</sup> of dry matter residue from legumes; LG6 - 12 Mg ha<sup>-1</sup> of dry matter residue from legumes and 6 Mg ha<sup>-1</sup> of gypsum; UG6 - 90 kg ha<sup>-1</sup> of N from urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG6 - 12 Mg ha<sup>-1</sup> of dry matter residue from legumes, 90 kg ha<sup>-1</sup> of N from urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG12 - 12 Mg ha<sup>-1</sup> of dry matter residue from legumes, 90 kg ha<sup>-1</sup> of N from urea, 12 Mg ha<sup>-1</sup> of gypsum. For better effect of comparison in physiological analysis of the maize, in

the year 2015 the plots of the control treatment were divided in two treatments: C (Control) and U (100 kg ha<sup>-1</sup> of N from urea). The results showed that the combination of gypsum with leguminous plants residue modified the root zone by increasing the calcium and organic matter levels and by reducing the soil penetration strength. For the maize, these changes increased the leaf area index and the remobilization of nitrogen to grains due to greater uptake before and after tasseling. This positive effect on physiological process produced also variations in yield maize. For example, the difference in yield between the treatments U, and LG6 (4.33 to 6.33) suggests that, rather than the increase of mineral fertilization alone, the combination gypsum with leguminous residues is a more suitable strategy to become feasible the agrosystems in cohesive soil of humid tropic.

**Keywords:** calcium, carbon, penetration strength, nitrogen remobilization, sandy loam soil.

## 1. Introduction

Cohesive soils derived of clastic sedimentary rock, with low contents of aggregators elements, like calcium and elemental iron, are widely spread in tropical world ([Daniells, 2012](#)). In cohesive soils the crops could be able exploit just a thin surface layer to sustain development, due to increase of fine particle and decrease organic carbon in depth, which became the deeper layer hard and inhospitable to root growth. In this circumstances, rooting depth-affected by any subsoil constraints can be a limit to crops growth when the stock of water and nutrients is not sufficient in this soil volume ([Wong and Asseng, 2007](#)).

In tropical condition, due to the high atmospheric evaporative demand, the actual transpiration rate may be less than the potential transpiration rate even with high soil water potential, which can lead the loss of turgidity, decreased carbon uptake, growth and yield crops ([Denmead and Shaw, 1960](#)). [Benjamin et al. \(2003\)](#) suggested a soil physical indicator symbolized by the expression 'water stress day' to design the total number of days when soil moisture contents is sufficiently low to cause crop water stress. In cohesive sandy loam soil in tropical region, it can be added from the fourth days without rain or irrigation ([Moura et al., 2012](#)).

The uptake of nutrients by crops is closely related to rootability conditions in the soil: higher root length densities lead to higher nutrients uptaken and less leaching, mainly in weathering tropical soils due to the high rainfall and the low nutrients retention capacity ([Dechert et al., 2005](#)). Therefore, enhancing the volume of soil explored by the crops is crucial to increase water and nutrient use efficiency and to enhance feasibility of the crops systems in the tropic region.

Strategies to reduce cohesion and enhance the soil rootability have been recommended through appropriate application of some techniques including: a) mechanical loosening such as deep ripping; b) by incorporating biomass in the soil c) use of mulching; and d) gypsum application ([Mulumba and Lal, 2008](#); [Sumner, 2009](#); [Badorreck et al., 2015](#); [Carrizo et al., 2015](#)). Ripping cohesive soil without removing the causes of compaction might not improve yield. Each time the soil is tilled, it is aerated which reduces the organic matter level and accelerates the process of re-compaction, increasing strength in cohesive soil after a year or less ([Busscher et al., 2002](#); [Moussadek et al., 2014](#)). Unfortunately, in tropical region accumulation of humified organic matter, by incorporating biomass in the soil, which



could mitigate negative effect of cohesion on soil rootability, is impaired by favourable conditions to decay the biomass ([Christensen, 2000](#)).

Mulching with surface residues has been recommended by providing soil cover and by decreasing the water evaporation rate, delaying soil moisture loss and improving soil rootability ([Moura et al., 2014](#)). Furthermore, the presence of polysaccharides and fungal activity linked to the production of proteins of the glomalin type derived of residue addition has been relevant in reducing soil disintegration, mainly the slaking mechanisms ([Carrizo et al., 2015](#)). However, as it has been observed that increased temperature and precipitation frequently correlate with accelerated rates of biomass decay, which can lead to loss of useful products from decomposition ([Wieder et al., 2009](#)). In addition, improvements in soil structural properties with crop residue mulch may only be significant near the soil surface ([Blanco-Canqui and Lal, 2007](#)).

To extend rootability to lower soil depths, some authors recommend the use of calcium as a “flocculating” agent to improve soil structure by reducing the dispersion of the clay ([Anikwe and Ibudialo, 2016](#); [Moura et al., 2016](#)). However, is still controversial the effect of calcium on aggregation that it seems to be positive only in dominated by sandy-kaolinitic or clayey-kaolinitic soil ([Wuddivira and Camps-Roach, 2007](#)). Although, some authors have emphasized positive interactions between calcium and organic matter compost derived of residue, which could enhance soil structure in the root zone ([Wuddivira and Camps-Roach, 2007](#); [Whittinghill and Hobbie, 2012](#)).

In turn, nutrient retention, mainly nitrogen, in the root zone can be enhanced where biologically mediated processes are utilized for nutrient release and nitrogen is

added in slow release forms. These approaches may be better at sustaining agrosystems in the humid tropics than the saturation of soil solution with soluble nutrients (Drinkwater and Snapp, 2007). Furthermore, a steady release of nitrogen from residue decomposition during the crop cycle, including the post-tasseling stage, is more important than rapid early availability to achieve of high crop productivity under leaching conditions (Moura et al., 2010).

Therefore, we hypothesised that use of gypsum combined with leguminous residue applied in soil surface may impart soil improvement effects, extending thickness of rootable layer, enhancing nitrogen uptake by entire cycles and increasing growth and maize yield. The aim of this work was to evaluate the combined effects of gypsum with residue from leguminous on calcium and C-organic contents in the root zone and as that may affect soil penetration strength, nitrogen uptake and maize yield 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 five growing seasons (2011, 2012, 2013, 2014 and 2015) at Maranhão State University, Brazil (2°30'S, 44°18'W). The region has a hot and semi-humid equatorial climate with two well-defined seasons: a rainy season that extends from January to June and a dry season with a marked water deficit from July to December. The annually mean rainfall (mm) during the experimental period was 1439 mm year<sup>-1</sup>. The average temperature during the

experimental period was approximately 27 °C, the maximum temperature was 37 °C, and the minimum temperature was 23 °C.

The local soils displayed cohesive characteristics (Moura et al., 2012) and were classified as Arenic Hapludults. Before the implantation of the experimental area, in December of 2010, were determined the chemical and physical properties of soil, which following: pH 4.0 (in CaCl<sub>2</sub>); 20 g kg<sup>-1</sup> of organic-C; 15 mg dm<sup>-3</sup> of P; 25 mmol<sub>c</sub> dm<sup>-3</sup> of (Al + H); 15 mmol<sub>c</sub> dm<sup>-3</sup> of Ca; 9 mmol<sub>c</sub> dm<sup>-3</sup> of Mg; 1 mmol<sub>c</sub> dm<sup>-3</sup> of K; 50 mmol<sub>c</sub> dm<sup>-3</sup> of CEC; 50,0 % of percentage base saturation; 300 g kg<sup>-1</sup> of coarse sand, 545 g kg<sup>-1</sup> of fine sand, 61 g kg<sup>-1</sup> of silt; 90 g kg<sup>-1</sup> of clay. In January 2011 the area was limed with 1 Mg ha<sup>-1</sup> of surface-applied lime, corresponding to 390 and 130 kg ha<sup>-1</sup> of Ca and Mg, respectively. Only in this same period, natural gypsum was applied at a rate of 6 or 12 Mg ha<sup>-1</sup> in the predetermined plots to receive these treatments, which corresponds to 1020 and 2040 kg ha<sup>-1</sup> of Ca, respectively. The gypsum grain size was such that 95% by weight passed through a 0.25-mm screen mesh.

The experiment was conducted under no-tillage conditions following a randomized block design with four replications of the following treatments: control, C - no residue or gypsum; L - 12 Mg ha<sup>-1</sup> of dry matter residue from legumes; LG6 - 12 Mg ha<sup>-1</sup> of dry matter residue from legumes and 6 Mg ha<sup>-1</sup> of gypsum; UG6 - 90 kg ha<sup>-1</sup> of N from urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG6 - 12 Mg ha<sup>-1</sup> of dry matter residue from legumes, 90 kg ha<sup>-1</sup> of N from urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG12 - 12 Mg ha<sup>-1</sup> of dry matter residue from legumes, 90 kg ha<sup>-1</sup> of N from urea, 12 Mg ha<sup>-1</sup> of gypsum. In the year 2015 the plots of the control treatment were divided in two

treatments: C (Control) and U (100 kg ha<sup>-1</sup> of N from urea). The treatment Urea was created for better effect of comparison only in physiological analysis of the maize.

Maize (cultivar AG 7088) was sown in the beginning of the rainy season in 2011, 2012, 2013 and 2015, with spacing 80 cm between rows and 25 cm between plants. In January of 2014, was sown soybean as crop rotation. The fertilization for maize and soybean consisted in the application of 80 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> from triple superphosphate, 120 kg ha<sup>-1</sup> of K<sub>2</sub>O from potassium chloride and 5 kg ha<sup>-1</sup> of Zn in the form of zinc sulphate. Residues from *Gliricidia sepium* (gliricidia) and *Acacia mangium* (acacia) were applied at 6 Mg ha<sup>-1</sup> for each legume (a total of 12 Mg ha<sup>-1</sup> per year), rate that commonly applied in alley cropping systems according to [Aguiar et al. \(2010\)](#). The legume residues were applied in the years 2011, 2012, 2013, 2014 and 2015, in the form of fresh branches. The quality parameters of the gliricidia and acacia residues were as follows: a C/N ratio of 13.5 and 23.5; 35.1 and 22.2 g kg<sup>-1</sup> of N; 1.5 and 3.1 g kg<sup>-1</sup> of P; 5.0 and 5.1 g kg<sup>-1</sup> of K; 13.2 and 16.4 g kg<sup>-1</sup> of Ca; 2.5 and 3.2 g kg<sup>-1</sup> of Mg, respectively. Then the quantities of nutrients added per year in form of leguminous residues was: 342 kg ha<sup>-1</sup> of N, 27.2 kg ha<sup>-1</sup> of P, 60.6 kg ha<sup>-1</sup> of K, 177.6 kg ha<sup>-1</sup> of Ca, 33.0 kg ha<sup>-1</sup> of Mg. The total amount of urea and leguminous residues were divided and applied at the time of sowing and 45 days after planting.

## 2.2 Soil chemical and physical analyses

Soil samples were collected in June 2012, 2013, 2014 and 2015 at depths of 0-10, 10-20, 20-30 and 30-40 cm. Three replicates were collected using a Dutch auger. The samples from each point were passed through a 2-mm screen mesh 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. \(1986\)](#). The table of critical level defined by [Heckman \(2006\)](#) was used to construct the graph of the estimated soil calcium content. Portions of the samples collected at a depth of 0 – 10 and 10 – 20 cm were separated for determination of organic carbon following the method describe by [Tiessen and Moir \(1993\)](#). The table of critical level defined by [Hazelton and Murphy \(2007\)](#) was used to construct the graph of the estimated soil carbon content.

The soil penetration strength was measured at depths of 0 - 5 cm, 5 - 10 cm, 10 - 15 cm, 15 - 20 cm and 20 - 25 cm with three replicates per plot, in April of 2015, after 4 days without rain. The soil penetration strength was measured using a digital penetrometer ([Falker, Porto Alegre, Brasil](#)) with 1-cm gradations. The table of critical level defined by [Hazelton and Murphy \(2007\)](#) was used to construct the graph of the soil penetration strength. Soil moisture was determined by gravimetric method, using samples obtained in the same period of assessment of soil penetration strenght, at three points along the given line.

In the year 2015 only the control was sampled to represent the treatment without gypsum with bare soil. Urea treatment was not sampled for soil chemical and physical analyses.

### *2.3 Plant analysis, yields components and water stress days*

The analysis of plant tissue was performed only in the year of 2015. The leaf area index (LAI) was calculated using the area of each leaf from the formula  $0.75 \times \text{length} \times \text{width}$ . The values of length and width were obtained from the biometric

measurements of the largest leaf of ten plants per plot chosen randomly (Montgomery, 1911). Nitrogen accumulation amount was measured on two occasions: at tasseling (NT) (or approximately 1 week before anthesis) and at the physiological maturity stage. At each sampling, five plants from each plot were randomly selected and separated into leaves, stalks and, at the second sampling, reproductive components. All of these plant materials were dried at 60 °C for 3 - 4 days to obtain a constant weight. Subsamples were collected and ground to passed through a 1-mm screen mesh. Total N concentration determined in the maize following  $\text{H}_2\text{SO}_4$  -  $\text{H}_2\text{O}_2$  digestion according to the standard method described by Cottenie (1980). Based on the measurements of plant dry matter (DM) and N uptake, we calculated the N remobilization (NR):  $[(\text{DM in all vegetative organs at tasseling} \times \text{N concentration at tasseling}) - (\text{DM in all vegetative organs at maturity} \times \text{N concentration in all vegetative organs at maturity})]$ . The amount of N uptaken post-tasseling (NPT) was calculated:  $(\text{N accumulation amount in all organs at maturity} - \text{N accumulation amount in all organs at tasseling})$ .

The yields components was performed only in the year of 2015. The weight of the ears, number of grains per ear, and weight of grains were determined, and all of the values were adjusted according to moisture level of  $145 \text{ g kg}^{-1}$ . We determined the weight of 100 grains by weighing the grain on a scale with an accuracy of 0.0001 g. The yield of maize was determinate at the final harvest or at physiological maturity of each year, which was assessed in a  $12 \text{ m}^2$  area.

The climate data were collected in a Remote Automated Weather Station localized on side of experimental area. The water stress days were calculated

considering the number of days after four days without rain (Benjamin et al., 2003; Moura et al., 2009).

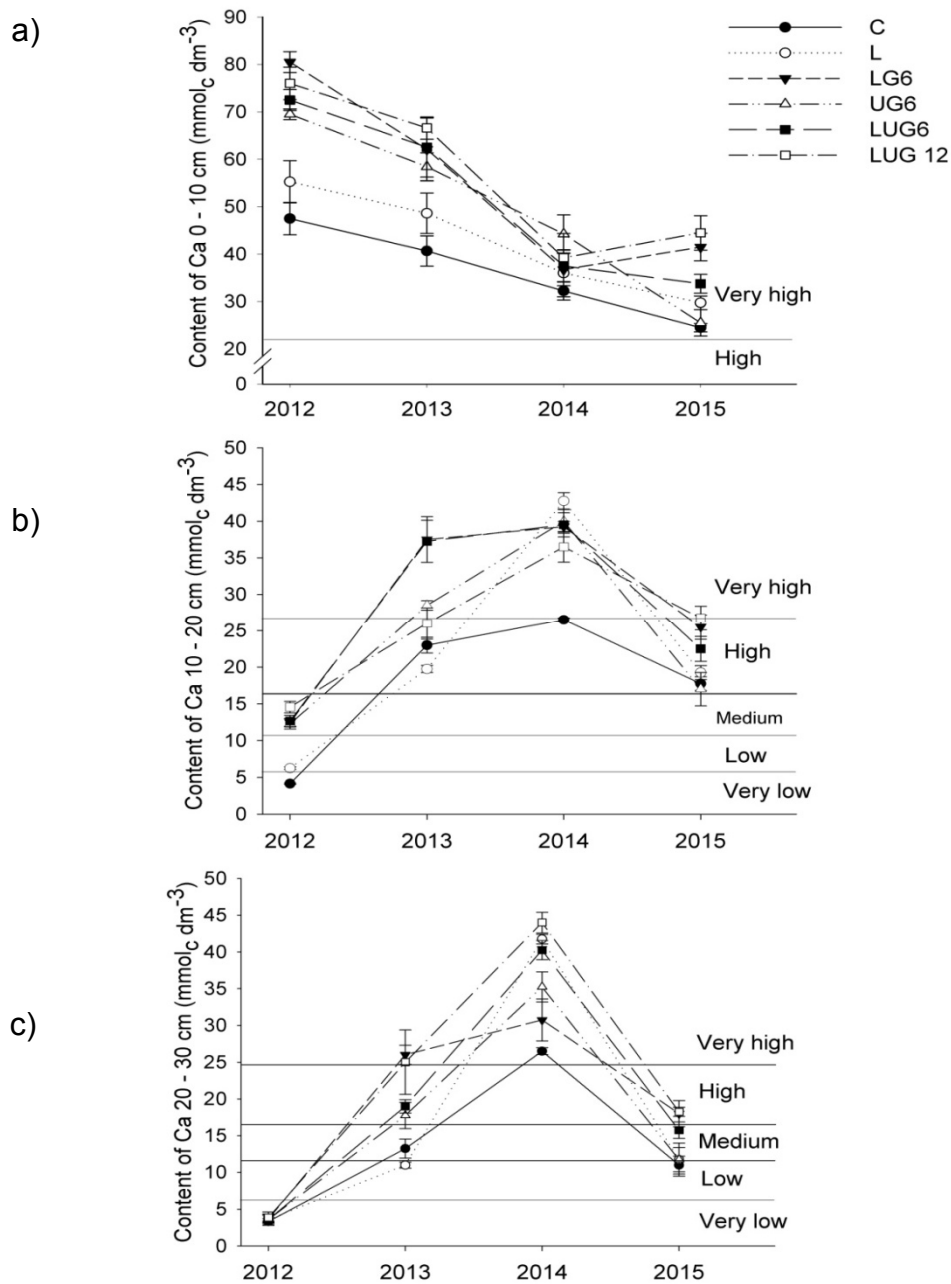
#### *2.4 Statistical analyses*

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

### **3. Results**

#### *3.1 Enhancement of soil rootability and responses in maize yield*

In the 0 – 10 cm layer the calcium concentration was increased by the application of gypsum just in the years 2012 and 2013 (Figure 1a). In the same layer in the year 2015, all treatments showed very high critical levels for calcium concentration, while in the 10 – 20 cm layer (Figure 1b) this concentration was high in all treatments. Five years after the application of gypsum and lime (2015), only in the treatment with gypsum without leguminous (UG6) the calcium concentration was not significantly higher from those with lime alone (C and L), up to the 30 cm depth. In the 20 – 30 cm deep (Figure 1c), these critical levels were low in the control, medium in L, LUG6 and UG6 and high in the treatments LG6 and LUG12. Only in the fourth year (2014) and in the 0 – 10 cm layer there was significant difference of calcium content between the treatments with 6 and 12 tons of gypsum.



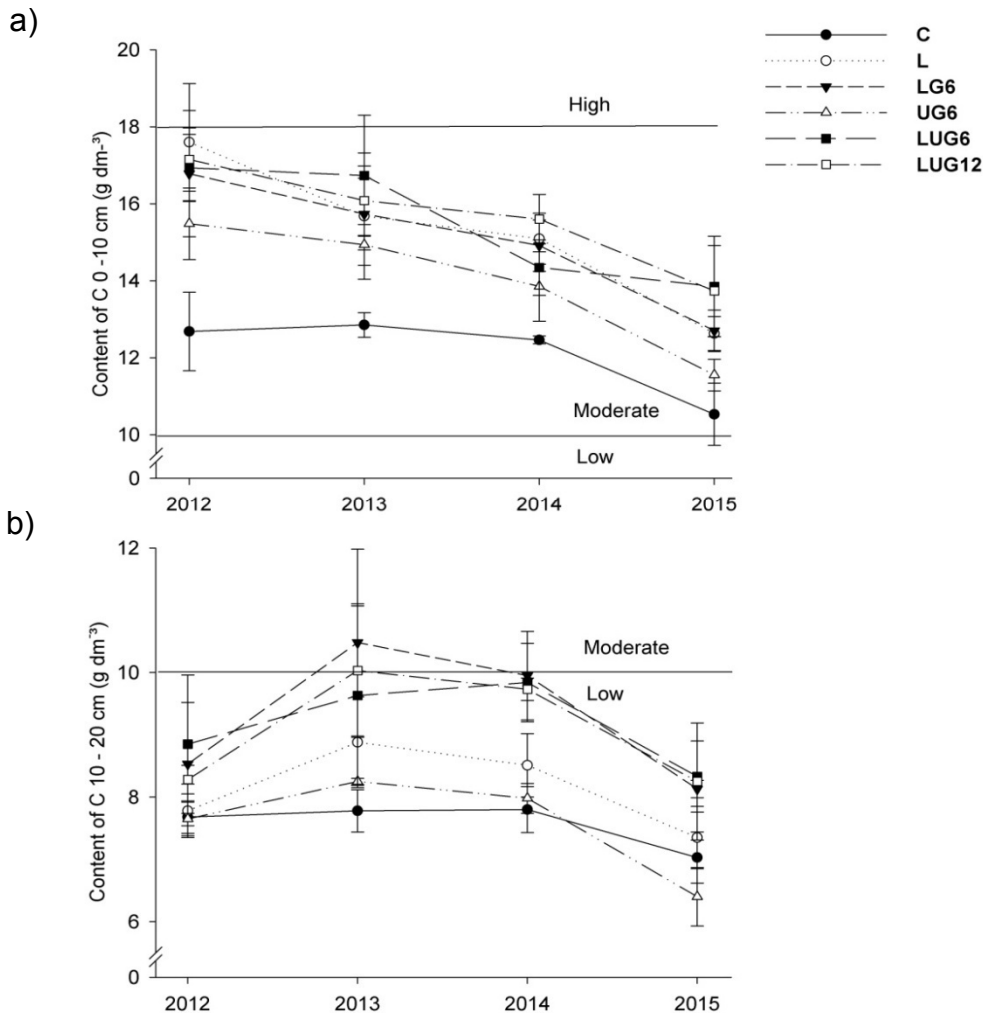
**Figure 1.**

Content of calcium in the soil, in the depth of 0-10 (a), 10-20 (b) and 20 – 30 (c) cm in 2012, 2013, 2014 and 2015. C= control ; L = leguminous; LG6 = leguminous and 6  $\text{Mg ha}^{-1}$  of gypsum; UG6 = urea and 6  $\text{Mg ha}^{-1}$  of gypsum; LUG6 = leguminous, urea and 6  $\text{Mg ha}^{-1}$  of gypsum; LUG12 = leguminous, urea and 12  $\text{Mg ha}^{-1}$  of gypsum. Bars show standard errors. Horizontal bars mean the critical levels by Heckman (2006).

In the plots with biomass of leguminous the C-organic was higher than in the uncovered plots. In the 0 – 10 cm layer the C-organic was higher no treatment UG6



than in the control treatment, with larger differences in the first years (Figure 2a). All treatments showed moderate critical levels of C-organic from the first until last year in the 0 – 10 cm layer, while it was low in the 10 – 20 cm layer (Figure 2b). There was no increase in C-organic from first to fourth years, even in the treatments with leguminous biomass.

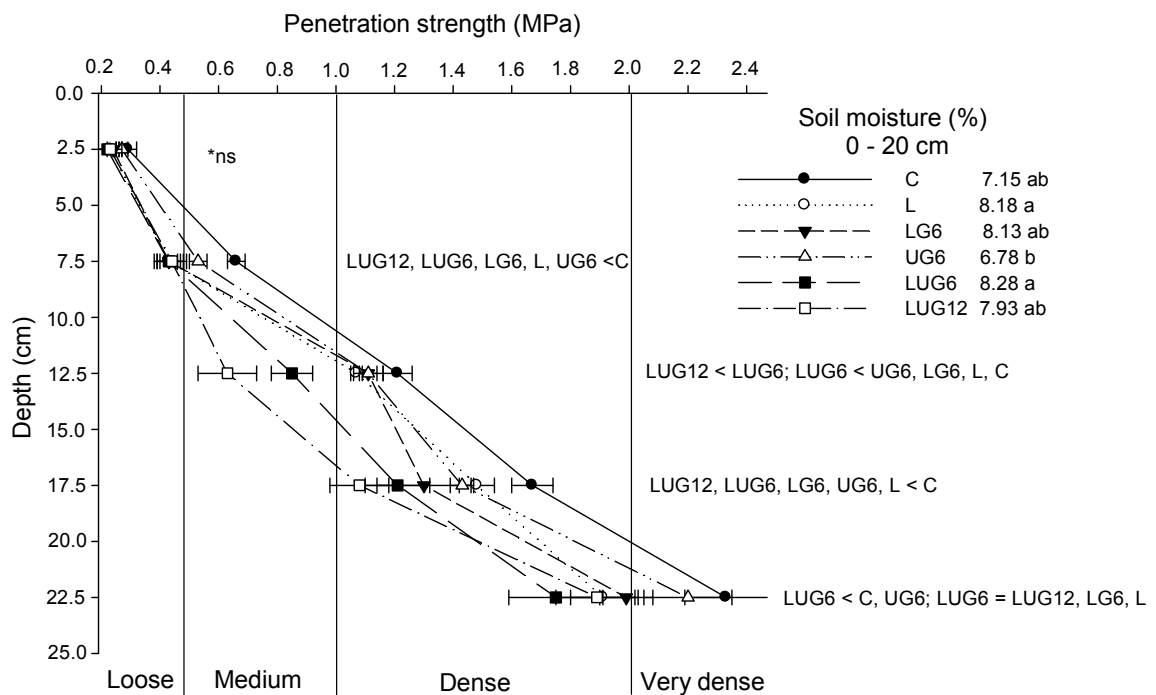


**Figure 2.**

Content of carbon in the soil, in the depth of 0 – 10 (a) and 10 – 20 (b) cm in 2012, 2013, 2014 and 2015. C= control ; L = leguminous; LG6 = leguminous and 6 Mg ha<sup>-1</sup> of gypsum; UG6 = urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG6 = leguminous, urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG12 = leguminous, urea and 12 Mg ha<sup>-1</sup> of gypsum. Bars show standard errors. Horizontal bars mean the critical levels by Hazelton and Murphy (2007).

The soil strength was lower in the plots with gypsum plus leguminous biomass in the 5 to 20 cm layer compared to the control plots (Figure 3). There was no significant difference among the treatments in the 0 – 5 cm layer where all treatments

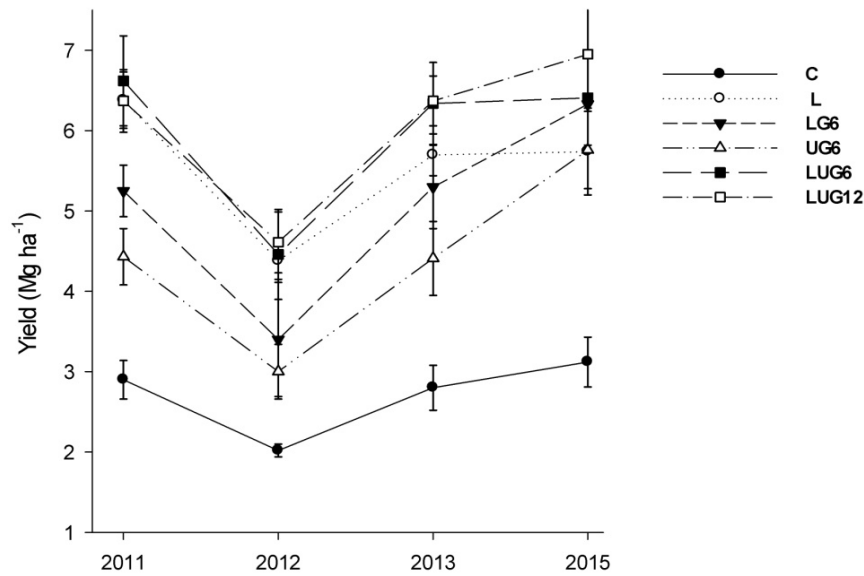
were loose. Except to LUG6 and LUG12, from the 10 – 15 cm layer all the treatments were dense four days after the rain. In the 20 – 25 cm layer, the treatments without cover were very dense. In the plots with gypsum, urea and leguminous, the effect of the gypsum on decreasing of soil strength was up to 25 cm, compared to the control.



**Figure 3.**

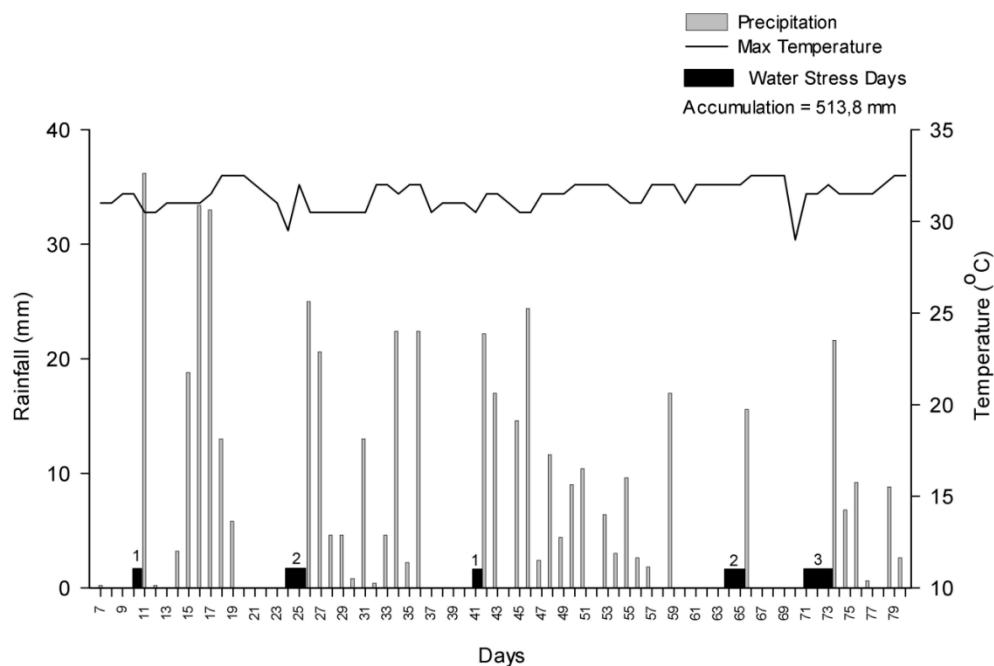
Penetration strength after 4 days without rain and gravimetric soil moisture in 2015. C= control ; L = leguminous; LG6 = leguminous and 6 Mg ha<sup>-1</sup> of gypsum; UG6 = urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG6 = leguminous, urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG12 = leguminous, urea and 12 Mg ha<sup>-1</sup> of gypsum. \*ns = not significant. Same letters in the soil moisture indicate no significant difference at the 5% level by Duncan's test. Vertical bars mean the critical levels by Hazelton and Murphy (2007).

The maize yield was impaired in 2012 in all treatments (Figure 4). In this year, the maize growing accumulated nine water stress days, five of which just in the grain filling stage (Figure 5). In the other years the water stress days were 3 in 2011, 2 in 2013 and 4 in 2015.



**Figure 4.**

Maize yield in the experimental area in 2011, 2012, 2013 and 2015. C= control ; L = leguminous; LG6 = leguminous and 6 Mg ha<sup>-1</sup> of gypsum; UG6 = urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG6 = leguminous, urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG12 = leguminous, urea and 12 Mg ha<sup>-1</sup> of gypsum. Bars show standard errors.



**Figure 5.**

Rainfall, maximum temperature (Max temperature) and water stress days in the experimental area during 6-80 days after sown of maize in 2012.

### 3.2 *The leaf area index (LAI), nutrient uptake and nitrogen remobilization.*

The leaf area index was larger in the treatments with leguminous and gypsum, without difference between them (Table 1). There was no significant difference between the treatments with urea and control. Differences in nitrogen uptake at tasseling and nitrogen remobilization were large and both leguminous and gypsum increased the nitrogen remobilized and accumulated in vegetative stage, so that  $L > C$  and  $UG6 > U$ . The nitrogen uptake at tasseling and the nitrogen remobilization were higher in the treatments with urea, leguminous and gypsum (LUG6, LUG12) and were lower in the plots without leguminous or gypsum (U, C). In the other treatments it were intermediated and without significant differences between them.

The greater amount of nitrogen uptake post-tasseling was showed by the treatments with leguminous. Thus, the treatment LG6 was 26 % superior to UG6 and L was 32 % superior to U. There was no difference between the treatments LUG12 and LG6. The nitrogen accumulation in the grain was also larger in the treatments with gypsum combined with leguminous. There was no difference among the treatments LUG12, LUG6, and LG6, which were superior to other treatments, except to L. Once again, the treatments U and control showed the lowest values of nitrogen accumulation of grain. The total N accumulated was greater in LUG12, LUG6, and LG6 than in U and control where it was not different. The dry matter at maturity was higher in the treatments with urea, leguminous and gypsum and it were lower in the plots without leguminous and gypsum.

**Table 1**

Leaf area index (LAI), nitrogen at tasseling (NT), nitrogen remobilized (NR), amount of nitrogen uptake post-tasseling (NPT), nitrogen of grain (NG), total nitrogen (TN), dry matter at maturity (DM), in the experimental area in 2015.

	<b>C</b>	<b>U</b>	<b>L</b>	<b>LG6</b>	<b>UG6</b>	<b>LUG6</b>	<b>LUG12</b>
<b>LAI (m<sup>2</sup> m<sup>-2</sup>)</b>	2.45 b	2.58 b	3.06 a	3.03 a	3.04 a	3.08 a	3.29 a
<b>NT (Kg ha<sup>-1</sup>)</b>	34.69 c	57.98 c	76.38 b	69.43 b	75.45 b	103.16 a	94.28 a
<b>NR (Kg ha<sup>-1</sup>)</b>	8.38 c	13.68 c	38.67 b	37.65 b	27.89 b	56.41 a	52.35 a
<b>NPT (Kg ha<sup>-1</sup>)</b>	27.24 c	28.00 c	41.19 ab	50.46 a	37.19 b	42.20 a	45.16 a
<b>NG (Kg ha<sup>-1</sup>)</b>	39.43 d	52.18 d	72.28 bc	88.35 ab	70.14 c	88.61 ab	94.50 a
<b>TN (Kg ha<sup>-1</sup>)</b>	61.93 c	85.98 bc	117.57 ab	119.89 a	112.64 ab	145.36 a	139.44 a
<b>DM (Mg ha<sup>-1</sup>)</b>	6.72 e	9.14 d	11.21 c	12.95 ab	11.37 bc	13.46 a	13.23 ab

C = control; U = urea; L = leguminous; LG6 = leguminous and 6 Mg ha<sup>-1</sup> of gypsum; UG6 = urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG6 = leguminous, urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG12 = leguminous, urea and 12 Mg ha<sup>-1</sup> of gypsum. Note: Different letters in the same row indicate differences at the 5% level by Duncan's test.

### 3.3 Maize yield components

Larger differences was showed by the weight of ear and number of grains per ear which was higher in LUG12 and LUG6 than in treatment with urea alone and control treatment, which showed the lowest values (Table 2). Differences in the weight of 100 grain among treatments were small and all the treatments were higher than the control, except to treatment with urea alone. The weight of grains was greater in the treatments LUG12, LUG6 and LG6, than in the treatments control and urea alone, which did not showed significant difference between them, but the UG6 and L treatments were superior to control.

**Table 2**

Weight of ear, number of grains ear<sup>-1</sup>, weight of 100 grains and weight of grains in the experimental area, 2015.

	C	U	L	LG6	UG6	LUG6	LUG12
<b>Weight of ear (g)</b>	118.48 c	162.10 b	188.71 ab	183.85 ab	190.61 ab	198.26 a	199.40 a
<b>Number of grains ear<sup>-1</sup></b>	447 c	555 b	619 ab	619 ab	618 ab	624 a	628 a
<b>Weight of 100 grains (g)</b>	26.24 b	28.99 ab	30.50 a	29.65 a	30.84 a	31.96 a	31.52 a
<b>Weight of grains (Mg ha<sup>-1</sup>)</b>	3.12 c	4.33 bc	5.74 ab	6.33 a	5.76 ab	6.41 a	6.95 a

C = control; U = urea; L = leguminous; LG6 = leguminous and 6 Mg ha<sup>-1</sup> of gypsum; UG6 = urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG6 = leguminous, urea and 6 Mg ha<sup>-1</sup> of gypsum; LUG12 = leguminous, urea and 12 Mg ha<sup>-1</sup> of gypsum. Note: Different letters in the same row indicate differences at the 5% level by Duncan's test.

#### 4. Discussion

The combination of the high rainfall levels of the study period ( 7194 mm ) with the high water infiltration rate of the soil can explain the fast downward movement of calcium in the soil profile ( [Figure 1](#) ). In the same soil, [Moura et al. \(2009\)](#) found water infiltration rate around 70 mm h<sup>-1</sup>. Furthermore, in most sandy loam soils with a small buffering capacity in which cations do not interact strongly with the soil matrix, the application Ca fertilizers results in a higher concentration in the soil solution that then may be leached if large amount of water move down into soil profile ( [Kolahchi and Jalali, 2007](#) ). This can explain also the small differences in calcium contents between the treatments with 6 or 12 tons per ha of gypsum. In contrast, the formation the cations bridge with products derived of decomposition of the biomass applied can account for the highest calcium level in the plots with leguminous. Polyvalent cation “bridges” can be formed between negatively charged particles, essentially binding organic molecules together or to minerals ( [Whittinghill and Hobbie, 2012](#) ). The major cation involved in the formation of bridges is Ca<sup>2+</sup>, therefore interactions between calcium organic macromolecules result in the formation of strong bonds involving

Ca<sup>2+</sup>-organic colloids. Furthermore, variation in exchangeable cation concentrations can affect fluxes of dissolved organic matter by stabilizing negatively charged organic matter through sorption to positively charged cations (Moore and Turunen, 2004). The bond between polyvalent cations and negatively charged organic matter functional groups is not easily reversible and surfaces of organic materials will be least accessible for microbial activity. This flocculated state preventing biological, chemical, or physical breakdown, which explains the differences in organic-C in the plots with gypsum, compared to treatment with leguminous alone (Figure 2) (Oste et al., 2002).

The soil strength above the 10 – 15 cm layer just 4 days after the rain (> 1.5 MPa), in control treatment, shows the necessity of enhancing the thickness of rootable layer (Figure 3). Provided that, the differences among treatments cannot be explained by small variation in soil moisture, the biomass and gypsum combined were able to improve the soil rootability. According to Shepherd et al. (2002), residue application may contribute to an environment favourable to root ability promoting the formation of 'ephemeral structures' in the structurally fragile by increasing the free light fraction of soil organic matter. In turn, the improvements caused by gypsum are both direct (increasing flocculation and aggregation in the subsoil) and indirect (improving root activity, which leads to greater soil aggregation) (Sumner, 2009). Anikwe and Ibudialo (2016) also reported the positive effect of gypsum on soil physical and chemical properties from a degraded tropical soil due to effect of Ca<sup>2+</sup> applied via gypsum to flocculate soil particles thereby creating an enabling soil physical condition. Furthermore, Wuddivira and Camps-Roach (2007) also reported that calcium in addition to organic matter can improve aggregation in a sandy-

kaolinitic soil by increasing aggregate stability resulted from the formation of strong bonds involving  $\text{Ca}^{2+}$  bridges, which increases the soil rootability.

It is worth highlight that one year after the application the leguminous and gypsum was not able to mitigate the impact of water stress days in the treatments with highest yield (Figure 4). Thus, in the 2012 the yield reflected the effect of the great number of water stress days this year, mainly during of the grain filled stage, which the soil amendment was not able to prevent (Figure 5).

The differences in the leaf area index showed that the mulch, more than gypsum or nitrogen applied, increased leaf expansion, which is one of the most sensitive processes to crop stress and can reduce the intercepted photosynthetically active radiation (Table 1). Dry matter production increases linearly with the amount of solar radiation intercepted by the current leaf area (Mbah and Eke-Okoro, 2015). According to Sadras and Milroy (1996), reduced leaf area is probably the most obvious mechanisms by which crops restrict water loss in response to soil-stress. Indeed, four days of water stress during the vegetative stage can have harmed the leaves growth in the uncovered plots in the year 2015. In turn, as the plants with mulch showed also higher accumulated N at tasseling stage, the increased leaf area index in the covered plots may also be due to greater nitrogen contents in leaves. During vegetative growth, N supply has a marked influence on leaf area development. The main effect is on leaf expansion due to increase in availability of cytokinins which plays a key role in leaf elongation rate through cell division, or cell elongation at the leaf base in young leaves (Sivasankar et al., 1997).

Both, leguminous and gypsum increased the N uptake at vegetative stage. Additionally, when combined (in LUG6), they increased more than twice the uptaken



N by the tasseling stage, compared to treatment with urea alone (Table 1). The absorption of N is highly dependent on root development and therefore of soil rootability, while root system growth results in greater uptake and less N leaching (Garnett et al., 2009). In the same way, the N remobilization was also affected by the gypsum and leguminous with large differences (around 85%) between LUG6 and C. As during the grain-filling period, nitrogen uptake is generally insufficient for the high demand of the seeds, remobilization in the different plant organs is needed to route nitrogen to the grains. The relative flow and remobilization of nitrogen to the grain during the grain-filling period can be analysed in terms of source of nitrogen to redistribution and sites to reutilization and storage (Masclaux-Daubresse et al., 2010). Therefore, the variation in the amounts of N remobilized was similar to those of N contents at tasseling stage. On the other hand, N depletion, especially in the leaves tends to accelerate the senescence of these, reducing the photosynthesis decreasing the weight of ear (Borrel et al., 2000). This reveals the importance of amount of nitrogen uptake post-tasseling, increased by the gypsum and leguminous combination. Difference of amount of N uptake pos-tasseling between the treatment LUG6 (42.20 Kg ha<sup>-1</sup>) and U (28.00 Kg ha<sup>-1</sup>) is crucial to demonstrate the positive effect of the combination gypsum-leguminous to N availability and uptake. Under strongly leaching condition only a sporadic supply of nitrogen in strips besides rows may not meet N demand of maize after tasseling stage (Moura et al., 2010). Therefore, a slowly releasing nutrient supply from decomposition of legumes residues and the enhancement of soil rootability made possible a higher N uptake, so that in LG6 (without urea) the total of N uptake was not different of LUG12 and LUG6 and was higher than in U. Both the urea and the leguminous increased the number of

grains per ear and the weight of ears but the weight of grain in LG6 was as high as in LUG6 which confirm the small effect of urea on the maize yield (Table 2). Indeed, while in U yield was not different of control in LG6 it was twice higher.

## 5. Conclusions

The results showed that the combination gypsum with leguminous residue modified the root zone by increasing the level of calcium and organic matter and by reducing the soil strength, when compared to other treatments. In the maize crop, these changes increased the leaf area index and the nitrogen remobilization to grains due to greater uptake before and after tasseling. This positive effect on physiological process produced also variations in yield maize. For example, the difference in yield between the treatments U, and LG6 (4.33 to 6.33) suggests that, rather than the increase of mineral fertilization alone, the combination gypsum with leguminous residues is a more suitable strategy to become feasible the agrosystems in cohesive soil of humid tropic.

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## **ANEXO**





## GUIDE FOR AUTHORS

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Give the meaning of all symbols immediately after the equation in which they are first used. For simple fractions use the solidus (/) instead of a horizontal line.

Equations should be numbered serially at the right-hand side in parentheses. In general only equations explicitly referred to in the text need be numbered.

The use of fractional powers instead of root signs is recommended. Also powers of e are often more conveniently denoted by exp.

Levels of statistical significance which can be mentioned without further explanation are: \*P <0.05,

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In chemical formulae, valence of ions should be given as, e.g., Ca<sup>2+</sup>, not as Ca<sup>++</sup>.

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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.

Reference to a website:

Cancer Research UK, 1975. Cancer statistics reports for the UK.

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