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

2016

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

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

São Luís

2016

STÉFANNY BARROS PORTELA

Engenheira Agrônoma

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

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

São Luís

2016

Portela, Stefanny Barros

Uso de gesso e residuos de leguminosas para melhorar a enraizabilidade de um solo tropical coeso e aumentar a produtividade do milho / Stefanny Barros Portela – São Luís, 2016.

54 f

Dissertação (Mestrado)– Curso de Agroecologia, Universidade Estadual do Maranhão, 2016.

Orientador: Profº Drº Emanoel Gomes de Moura

1.Cálcio. 2.Carbono . 3.Resistência a penetração do solo .4. Remobilização do nitrogênio.I.Título

CDU:631:633.15

STÉFANNY BARROS PORTELA

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

Aprovada em: _____/_____/____

BANCA EXAMINADORA

Prof. Dr. Emanoel Gomes de Moura (Orientador)
Universidade Estadual do Maranhão - UEMA

Prof. Dr. Heder Braun
Universidade Estadual do Maranhão - UEMA

Pesquisador Dr. João Batista Zonta
EMBRAPA - Cocais

São Luís

2016

DEDICO

A Deus, que é o provedor de tudo.

A meus pais pelo amor, educação e dedicação.

Aos meus irmãos pelo apoio e confiança.

Ao meu namorado pelo carinho e companheirismo.

Aos meus amigos pelo incentivo e força nessa jornada.

AGRADECIMENTOS

Tudo termina com começos, e é com extrema saudade que inicio a busca por novos desafios profissionais. Com essa jornada, adquiri não só uma experiência extraordinária para a minha carreira, mas conquistei amizades de pessoas incríveis, que partilharam suas histórias cotidianas que muito me inspiraram.

Gostaria de agradecer imensamente a todas as pessoas que de alguma forma me ajudaram. Sei que posso acabar esquecendo alguém, mas algumas delas merecem uma saudação a parte:

Em especial agradeço a Deus por guiar e iluminar os meus caminhos, me concedendo fé e sabedoria ao longo desta jornada.

À minha amada mãe que sempre me inspirou por sua história de luta, força e determinação e que me motivou na busca pelos meus objetivos.

Ao meu pai que contribuiu de forma incisiva na minha formação e na minha vida.

Aos meus irmãos Leandro e Júnior, meus parceiros de vida.

Ao meu namorado Frederico, pelo incentivo e palavras de força nos dias que precisava de conforto. Obrigada!

Aos meus amigos da pós graduação, em especial Virley, Vinícius, Franciele e Marta; agradeço a simpatia nas conversas descontraídas e principalmente a disposição em auxiliar nas minhas dúvidas de trabalho.

Ao Prof. Dr. Emanoel Gomes de Moura, pela orientação, incentivo e acompanhamento durante esta fase.

Ao professor João Reis, Dionísio e Neto que prontamente se disponibilizaram quando precisei.

A todo o corpo docente da Pós Graduação em Agroecologia, pelo conhecimento adquirido durante esses anos.

À CAPES pela concessão da bolsa de estudos.

À Universidade Estadual do Maranhão e a todos outros que não foram citados aqui, mas que contribuíram de alguma forma, fica aqui o meu grande abraço para todos vocês, pelas risadas, problemas resolvidos e desafios enfrentados. Muito obrigada!

“Tudo posso naquele que me fortalece.”

Filipenses 4, 13.

SUMÁRIO

Uso de gesso e resíduos de leguminosas para melhorar a enraizabilidade de um solo tropical coeso e aumentar a produtividade do milho

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

LISTA DE FIGURAS

LISTA DE TABELAS

Uso de gesso e resíduos de leguminosas para melhorar a enraizabilidade de um solo tropical coeso e aumentar a produtividade do milho

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 estendiam 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 ($CaSO_4 . 2H_2O$) no solo, aumenta a disponibilidade de Ca^{2+}, o que pode aumentar a atividade da raiz em camadas mais profundas, melhorar a estabilidade dos agregados e, consequentemente, 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_2), 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_2 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^{2+} para o complexo de troca onde Mg^{2+}, K^+ e o Na^+ 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).

REFERÊNCIAS BIBLIOGRÁFICAS

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

AGUIAR, A.C.F.; BICUDO, S.J.; SOBRINHO, J.R.S.C.; MARTINS, A.L.S.; COELHO, K.P.; MOURA, E.G. 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. 2010.

BARBIERI, P.A.; ECHEVERRÍA, H.E.; SAINZ ROZAS, H.R.; MARTÍNEZ, J.P. Soybean and wheat response to lime in no-till Argentinean mollisols. **Soil and Tillage Research,** v. 152, p. 29-38. 2015.

BAUDER, J.W.; MONTGOMERY, B.R. N-Source and irrigation Effects on Nitrate Leaching. **Agronomy Jounal**, v.72, p.593-596. 1980.

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

BEDDINGTON, J.R.; ASADUZZAMAN, M.; CLARK, M.; FERNANDEZ, A.; GUILOU, M.; JAHN, M.; ERDA, L.; MAMO, T.; VAN BO, N.; NOBRE, C.A.; SCHOLES, R.; SHARMA, R.; WAKHUNGU, J. **Achieving food security in the face of climate change:** final report from the commission on sustainable agriculture and climate change. CGIAR Research Program On Climate Change, Agriculture And Food Security (CCAFS), Copenhagen,Denmark. 2012.Disponível em: <http://www.ccafs.cgiar.org/commission>. Acesso em: 19 jan. 2016.

BLANCO-CANQUI, H.; LAL, R. Soil and crop response to harvesting corn residues for biofuel production. **Geoderma,** v. 141, p. 355-362. 2007.

BOUMAN, O.T.; CURTIN, D.; CAMPBELL, C.A.; BIEDERBECK, V.O.; UKRAINETZ, H. Soil acidification from long-term use of anhydrous ammonia and urea. **Soil Science Society of American Journal**, v. 59, p.1488-1494. 1995.

BRADY, N.C; WEIL, R.R. The nature and properties of soil. In: ______ . **Upper Saddle River**. New Jersey: Prentice-Hall Inc., Simona and Schuster A Viacon Company, 1999. p.960.

BRADY, N.C.; WEIL, R.R. The Nature and Properties of Soils. In: ______. **Macmillan Publishing Company**. New York: Simona and Schuster A Viacon Company, 1996. p.351-367.

CAIRES, E.F.; JORIS, H.A.W.; CHURKA, S. Long term 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. 2011.

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

CASSMAN, K.G.; DOBERMANN, A.; WALTERS, D.T. Agroecosystems, nitrogen-use efficiency, and nitrogen management. **Ambio,** v. 31, p. 132-140. 2002.

CASSMAN, K.G.; DOBERMANN, A.; WALTERS, D.T.; YANG, H. Meeting cereal demand while protecting natural resources and improving environmental quality. **Annual Review of Environment and Resources,** v. 28, p. 315-358. 2003.

CENTRE, J. I. **Nutrient use efficiency 2014.** Disponível em: <https://www.jic.ac.uk/staff/stanislav-kopriva/nutrient_use_efficiency.htm> , Acesso: 10 jan. 2016.

CHANEY, K.; SWIFT, R.S. The influence of organic matter on aggregate stability in some British soils. **Journal of Soil Science**. v. 35, p. 223-230. 1984.

CHARTRES, C.J.; KIRBY, J.M.; RAUPACH, M. Poorly Ordered Silica and Aluminosilicates as Temporary Cementing Agents in Hard-Setting Soils. **Soil Science Society of America Journal**, v. 54, p.1060-1067. 1990.

COLEMAN, D.C.; ODUM, E.P.; CROSSLEY, D.A. Soil biology, soil ecology, and global change. **Biology and Fertility of Soils,** v. 14, p. 104-111. 1992.

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

DAHIYA, R.; INGWERSEN, J.; STRECK, T. The effect of mulching and tillage on the water and temperature regimes of a loess soil: Experimental findings and modeling. **Soil and Tillage Research**, v. 96, p. 52–63. 2007.

DE WIT, CT. Resource use efficiency in agriculture. **Agricultural Systems**, v. 40, p. 125-151. 1992.

DOBERMANN, A.; CASSMAN, K. Plant nutrient management for enhanced productivity in intensive grain production systems of the United States and Asia. **Plant and Soil,** v. 247, p. 153-175. 2002.

DOBERMANN, A.; WITT, C.; DAWE, D. Increasing productivity of intensive rice systems through site-specific nutrient management. In: ______. **Science Publishers**. New Delhi: International Rice Research Institute, 2002. p. 410.

DONTSOVA, K.M.; NORTON, L.D. Clay dispersion, infiltration and erosion as influenced by exchangeable Ca and Mg. **Soil Science**, v. 163, p.184–193. 2002.

DRINKWATER, L.E.; SNAPP, S.S. Nutrients in agroecosystems: rethinking the management paradigm. **Advances in Agronomy**, v. 92, p. 163–186. 2007.

FAO. The State of Food Insecurity in the World . *Meeting the 2015 international hunger targets: taking stock of uneven progress.* Rome, 2015. Disponível em: <http://www.fao.org/publications>. Acesso: 10 jan. 2016.

FAVARETTO, N. **Gypsum amendment and exchangeable calcium and magnesium related with water quality and plant nutrition**. 2002. Ph.D. dissertation - Purdue University, [2002].

FLANAGAN, D.; NORTON, L.D.; SHAINBERG, I. Effect of water chemistry and soil amendments on a silt loam soil: part 1: infiltration and runoff. **Transactions of ASAE**, v. 40, p.1549–1554. 1997.

GAIFFE, M.B.; DUQYET, H.; TAVANT, Y.; TAVANT, S. Stabilite biologique et comportement physique d'un complexe argilo-humique place dan differentes conditions de saturation en calcium and potassium. **Plant and Soil**, v. 77, p. 271-284. 1984.

GALLOWAY, J.N.; COWLING, E. Reactive nitrogen and the world: 200 years of change. **Ambio**, v. 31, p. 64-71. 2002.

GLINSKI, J.; STÊPNIEWSKI, W. Soil aeration and its role for plants. **Boca Raton**: CRC Press, p. 229. 1986.

GODFRAY, H.C.J.; BEDDINGTON, J.R.; CRUTE, I.R.; HADDAD, L.; LAWRENCE, D.; MUIR, J.F. Food security: the challenge of feeding 9 Billion people. **Science**, v. 327, p. 812-818. 2010.

GRAHAM, R.D. Breeding for nutritional characteristics in cereals. **Advances in Plant Nutrition**, v. 1, p. 57-102. 1984.

GREENWOOD, D.J.; LEMAIRE, G.; GOSSE, G.; CRUZ, P.; DRAYCOTT, A.; NEETSON, J.J. Decline in percentage N of C_3 and C_4 crops with increasing plant mass. **Annals of Botany**, v. 66, p.425-436. 1990.

HOCHMAN, Z.; CARBERRY, P.S.; ROBERTSON, M.J.; GAYDON, D.S.; BELL, L.W.; MCINTOSH, P.C. Prospects for ecological intensification of Australian agriculture. **European Journal of Agronomy**, v. 44, p. 109-123. 2011.

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

KEATING, B.A.; CARBERRY, P.S.; BINDRABAN, P.S.; ASSENG, S.; MEINKE, H.; DIXON, J. Eco-efficient agriculture: concepts, challenges and opportunities. **Crop Science**, v. 50, p.109-119. 2010.

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

LEY, G.J.; MULLINS, C.E.; LAL, R. The potential restriction to root growth in structurally weak tropical soils. **Soil and Tillage Research**, v. 33, p. 133–142. 1995.

MATSON, P.A.; PARTON,W.J.; POWER, A.G.; SWIFT, M.J. Agricultural intensification and ecosystem properties. **Science**, v. 277, p. 504-509. 1997.

McDONALD, R.C.; ISBELL, R.F.; SPEIGHT, J.G.; WALKER, J.; HOPKINS, M.S. Infiltration and soil loss of three gypsum amended Ultisols under simulated rainfall. **Soil Science Society of American Journal**, v. 55, p. 783–787. 1990.

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

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

MOURA, E.G.; OL IVEIRA, A.K.; COUTINHO, C.G.; PINHEIRO, K.M.; AGUIAR, A.C.F. 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. 2012.

MOURA, E.G.; SENA, V.G.L.; SOUSA, C.C.M.; SILVA, F.R.; COELHO, M.J.A.; MACEDO, V.R.A.; AGUIAR, A.C.F. Enhancement of the rootability of a structurally fragile tropical soil using gypsum and leguminous residues to increase the maize yield. **Soil Use and Management**, v. 32. 2016.

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

MOUTIER, M.; SHAINBERG, I.; LEVY, G.J. Hydraulic gradient, aging, and water quality effects on the hydraulic conductivity of a vertisol. **Soil Science Society of American Journal**, v. 62, p.1488–1495. 1998.

MULLINS, C.E. Hardsetting soils. In: ______. **Handbook of soil science**. New York: CRC Press, 1999. p. 65-87.

MULLINS, C.E. Hardsetting. Methods for assesment of soil degradation. **Advances in Soil Science**, CRC Press, p.109-128. 1997.

MULLINS, C.E.; CASS, A.; MacLEOD, D.A.; HALL, D.J.M.; BLACKWELL, P.S. Strength development during drying of a cultivated, flood-irrigated hardesetting soil. II. Trangie soil, and comparison with theorical predictions. **Soil and Tillage Research**, v. 25, p.129-147. 1992.

MULLINS, C.E.; MACLEOD, D.A.; NORTHCOTE, K.H.; TISDALL, J.M.; YOUNG, I.M. Hardsetting soils: behaviour, ocurrence and management. **Advances in Soil Science**, v.11, p.37-108. 1990.

NELSON, G.C.; ROSEGRANT, M.W.; PALAZZO, A.; GRAY, I.; INGERSOLL, C.; ROBERTSON, R.; TOKGOZ, S.; ZHU, T.; SULSER, T.B.; RINGLER, C.; MSANGI, S.; YOU, L. Food security, farming, and climate change to 2050: scenarios, results, policy options. **International Food Policy Research Institute**,Washington, p.140. 2010.

NORTON, L.D.; DONTSOVA, K. Use of soil amendments to prevent soil surface sealing and control erosion. **Advances in Geoecology**, v. 31, p. 581–587. 1998.

NORTON, L.D.; ZHANG, X.C. Liming to improve chemical and physical properties of soil. In: ______. **Handbook of Soil Conditioners:** Substances that Enhance Physical Properties of Soil. New York: Marcel Dekker, 1998. p.309–331.

OADES, J.M. The retention of organic matter in soils. **Biogeochemistry**, v. 5, p. 35-70. 1988.

OBADE, P.V.; LAL, RATTAN. Using meta-analyses to assess pedo-variability under different land uses and soil management in central Ohio,USA. **Geoderma**, v. 232-234, p. 56-68. 2014.

ONU. World Population Prospects: The 2008 Revision. Highlights, New York, p.107. 2009.

OSTER, J.; SHAINBERG, I.; ABROL, I.P. Reclamation of salt-affected soils. **Agricultural Drainage**, p. 659–691. 1999.

PENG, S.; GARCIA, F.V.; LAZA, R.C.; SANICO, A.L.; VISPERAS, R.M.; CASSMAN, K.G. Increased N-use efficiency using a chlorophyll meter on high-yielding irrigated rice. **Field Crops Research**, v. 47, p. 243-252. 1996.

PINGALI, P.L. Green revolution: impacts, limits, and the patha head. **Proceedings of National Academy Science U.S.A.**, v.109, p.12302-12308. 2012.

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

RUSINAMHODZI, L.; CORBEELS, M.; VAN WIJK, M.T.; RUFINO, M.C.; NYAMANGARA, J.; GILLER, K.E. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. **Agronomy for Sustainable Development**, DOI 10.1007/s13593-011-0040-2. 2011.

SAINZ ROZAS, H.R.; CALVIÑO, P.A.; ECHEVERRÍA, H.E.; BARBIERI, P.A.; REDOLATTI, M. Contribution of anaerobically mineralized nitrogen to planting or pre sidedress soil nitrogen test in maize. **Agronomy Journal**, v.100, p.1020-1025. 2008.

SAINZ ROZAS, H.R.; ECHEVERRÍA, H.E.; ANGELINI, H.P. Niveles de carbono orgánico y pH em suelos agrícolas de laregión pampeana y extra pampeana argentina. **Ciencia del Suelo**, v. 29, p. 29-37. 2011.

SAROA, G.S.; LAL, R. Soil restorative effects of mulching on aggregation and carbon sequestration in a Miamian soil in Central Ohio. **Land Degradation and Development**, v.14, p.481–493. 2003.

SHAINBERG, I.; SUMNER, M.E.; MILLER, W.P.; FARINA, M.P.W.; PAVAN, M.A.; FEY, M.V. Use of gypsum on soils: a review. **Advances in Soil Science**, p. 2–111. 1989.

SHOJI, S.; KANNO, H. Use of polyolefin-coated fertilizers for increasing fertilizer efficiency and reducing nitrate leaching and nitrous oxide emissions. **Fertilizer Research**, v.39, p.147-152. 1994.

SUMNER, M.E. Amelioration of subsoil acidity with minimum disturbance. **Lewis Public**, p.147-185. 1995.

SUMNER, M.E. Gypsum as an Ameliorant for the Subsoil Acidity Syndrome. **Florida Institute of Phosphate Research**, Bartow, FL. 1990.
TAIZ, L.; ZEIGER, E. In: ______. **Fisiologia Vegetal**. 5. ed. Porto Alegre: Artmed, 2013. p.918.

TARKALSON, D.D.; HERGERT, G.W.; CASSMAN, K.G. Long-term effects of tillage on soil chemical properties and grain yields of dryland winter wheat–sorghum/ corn–fallow rotation in the Great Plains. **Agronomy Journal**, v. 98, p. 26-33. 2006.

TILMAN, D.; BALZER, C.; HILL, J.; BEFORT, BL. Global Food demand and the sustainable intensification of agriculture. **Proceedings of the National Academy of Sciences**, v.108, p.20260-20264. 2011.

TILMAN, D.; CASSMAN, KG.; MATSON, PA.; NAYLOR, R.; POLASKY, S. Agricultural Sustainability and intensive production practices. **Nature**, v.418, p.671-677. 2002.

TIRADO-CORBALA, R.; SLATER, B.K.; DICK, W.A.; BIGHAM, J.; MCCOY, E. Hydrologic properties and leachate nutrient responses of soil columns collected from gypsum-treated fields. **Soil and Tillage Research**, v. 134, p. 232–240. 2013.

TOPP, G.C.; REYNOLDS, W.D.; COOK, F.J.; KIRBY, J.M.; CARTER, M.R. **Developments in Soil Science**, v. 25, p. 21–58. 1997.

VANCE, C.P.; UNDE-STONE, C.; ALLAN, D.L. Phosphorus acquisition and use: critical adaptation by plants for securing a nonrenewable resource. **New Phytologist**, v.157, p. 423-447. 2003.

VÁZQUEZ, M.; TERMINIELLO, A.; DUHOUR, M.A.; GARCÍA, M.; GUILINO, F. Efect odelencalado sobre propiedades físicas de um suelo de la pradera pampeana: asociación com propiedades químicas. **Cienc del Suelo**, v.27, p.67–76. 2009.

VELASCO, J.L.; SAINZ ROZAS, H.R.; ECHEVERRÍA, H.E.; BARBIERI, P.A. Optimizing fertilizer nitrogen use efficiency by intensively managed spring wheat in humid regions: effect of split application. **Canadian Journal of Plant Science**, v. 92, p. 847-852. 2012.

WEAICH, K.; BRISTOW, K.L.; CASS, A. Pre-emergent shoot growth of maize under different drying conditions. **Soil Science Society of America Journal**, v.56, p.1272-1278. 1992.

WHITTINGHILL, K.A.; HOBBIE, S.E. Effects of pH and calcium on soil organic matter dynamics in Alaskan tundra. **Biogeochemistry**, v.111, p.569–581. 2012.

WONG, M.T.F.; ASSENG, S. Yield and environmental benefits of ameliorating subsoil constraints under variable rainfall in a Mediterranean environment. **Plant Soil**, v. 297, p. 29-42. 2007.

YOUNG, I.M.; MULLINS, C.E.; COSTIGAN, P.A.; BENGOUGH, A.G. Hardsetting and structural regeneration in two unstable Britsh sandy loams and their influence on crop growth. **Soil and Tillage Research**, v. 19, p. 383-394, 1991.

ZHANG, H.Q.; HARTGE, K.H. Mechanical properties of soils as influenced by incorporated organic matter. **Advances in Soil Science**: Soil Structure, its Development and Function, p. 98–100. 1995.

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

---

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

S. B. Portela[1], E. G. Moura[1]

[1] *Programa de Pós-Graduação em Agroecologia, Universidade Estadual do Maranhão, 65054-970 São Luís, Maranhão, Brazil.*

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^{-1} of dry matter residue from legumes; LG6 - 12 Mg ha^{-1} of dry matter residue from legumes and 6 Mg ha^{-1} of gypsum; UG6 - 90 kg ha^{-1} of N from urea and 6 Mg ha^{-1} of gypsum; LUG6 - 12 Mg ha^{-1} of dry matter residue from legumes, 90 kg ha^{-1} of N from urea and 6 Mg ha^{-1} of gypsum; LUG12 - 12 Mg ha^{-1} of dry matter residue from legumes, 90 kg ha^{-1} of N from urea, 12 Mg ha^{-1} 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^{-1} 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^{-1}. The average temperature during the experimental period was approximately 27 ºC, the maximum temperature was 37 ºC, and the minimum temperature was 23 ºC.

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 $CaCl_2$); 20 g kg^{-1} of organic-C; 15 mg dm^{-3} of P; 25 $mmol_c$ dm^{-3} of (Al + H); 15 $mmol_c$ dm^{-3} of Ca; 9 $mmol_c$ dm^{-3} of Mg; 1 $mmol_c$ dm^{-3} of K; 50 $mmol_c$ dm^{-3} of CEC; 50,0 % of percentage base saturation; 300 g kg^{-1} of coarse sand, 545 g $kg^{-1}$of fine sand, 61 g kg^{-1} of silt; 90 g kg^{-1} of clay. In January 2011 the area was limed with 1 Mg ha^{-1} of surface-applied lime, corresponding to 390 and 130 kg ha^{-1} of Ca and Mg, respectively. Only in this same period, natural gypsum was applied at a rate of 6 or 12 Mg ha^{-1} in the predetermined plots to receive these treatments, which corresponds to 1020 and 2040 kg ha^{-1} 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^{-1} of dry matter residue from legumes; LG6 - 12 Mg ha^{-1} of dry matter residue from legumes and 6 Mg ha^{-1} of gypsum; UG6 - 90 kg ha^{-1} of N from urea and 6 Mg ha^{-1} of gypsum; LUG6 - 12 Mg ha^{-1} of dry matter residue from legumes, 90 kg ha^{-1} of N from urea and 6 Mg ha^{-1} of gypsum; LUG12 - 12 Mg ha^{-1} of dry matter residue from legumes, 90 kg ha^{-1} of N from urea, 12 Mg ha^{-1} of gypsum. In the year 2015 the plots of the control treatment were divided in two treatments: C (Control) and U (100 kg ha^{-1} 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^{-1} of P_2O_5 from triple superphosphate, 120 kg ha^{-1} of K_2O from potassium chloride and 5 kg ha^{-1} of Zn in the form of zinc sulphate. Residues from *Gliricidia sepium* (gliricidia) and *Acacia mangium* (acacia) were applied at 6 Mg ha^{-1} for each legume (a total of 12 Mg ha^{-1} 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^{-1} of N; 1.5 and 3.1 g kg^{-1} of P; 5.0 and 5.1 g kg^{-1} of K; 13.2 and 16.4 g kg^{-1} of Ca; 2.5 and 3.2 g kg^{-1} of Mg, respectively. Then the quantities of nutrients added per year in form of leguminous residues was: 342 kg ha^{-1} of N, 27.2 kg ha^{-1} of P, 60.6 kg ha^{-1} of K, 177.6 kg ha^{-1} of Ca, 33.0 kg ha^{-1} 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 x length x 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 ºC 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 H_2SO_4 - H_2O_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): [(DM in all vegetative organs at tasseling x N concentration at tasseling) – (DM in all vegetative organs at maturity x N concentration in all vegetative organs at maturity)]. The amount of N uptaken pos-tasseling (NPT) was calculated: (N accumulation amount in all organs at maturity – 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 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 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.

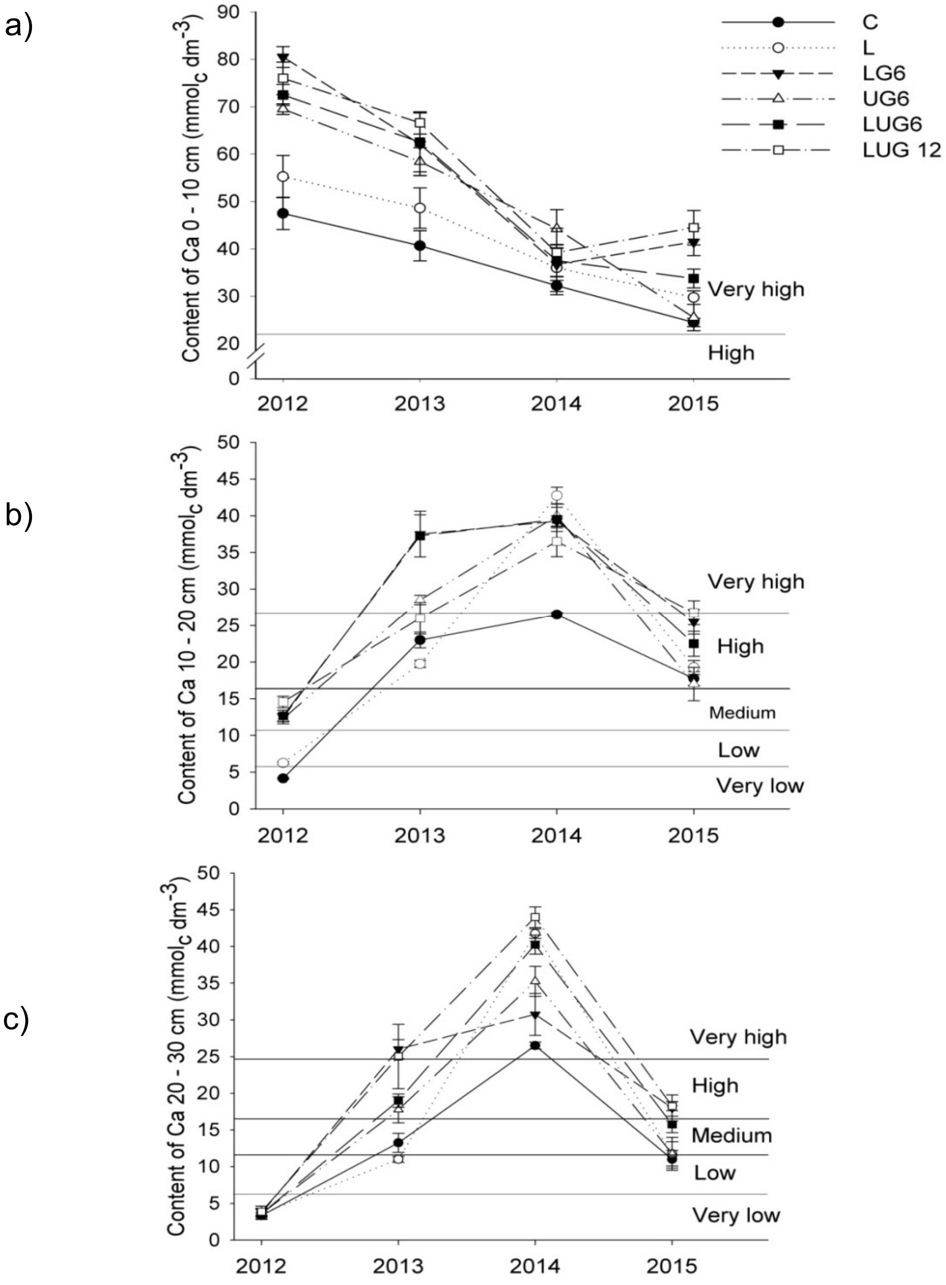

Figure 1.
Content of calcium in the soil, in the depth of 0-10 (a), 10-20 (b) and 20 – 30 (c) cm in 2012, 2013, 2014 and 2015. C= control ; L = leguminous; LG6 = leguminous and 6 Mg ha^{-1} of gypsum; UG6 = urea and 6 Mg ha^{-1} of gypsum; LUG6 = leguminous, urea and 6 Mg ha^{-1} of gypsum; LUG12 = leguminous, urea and 12 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.

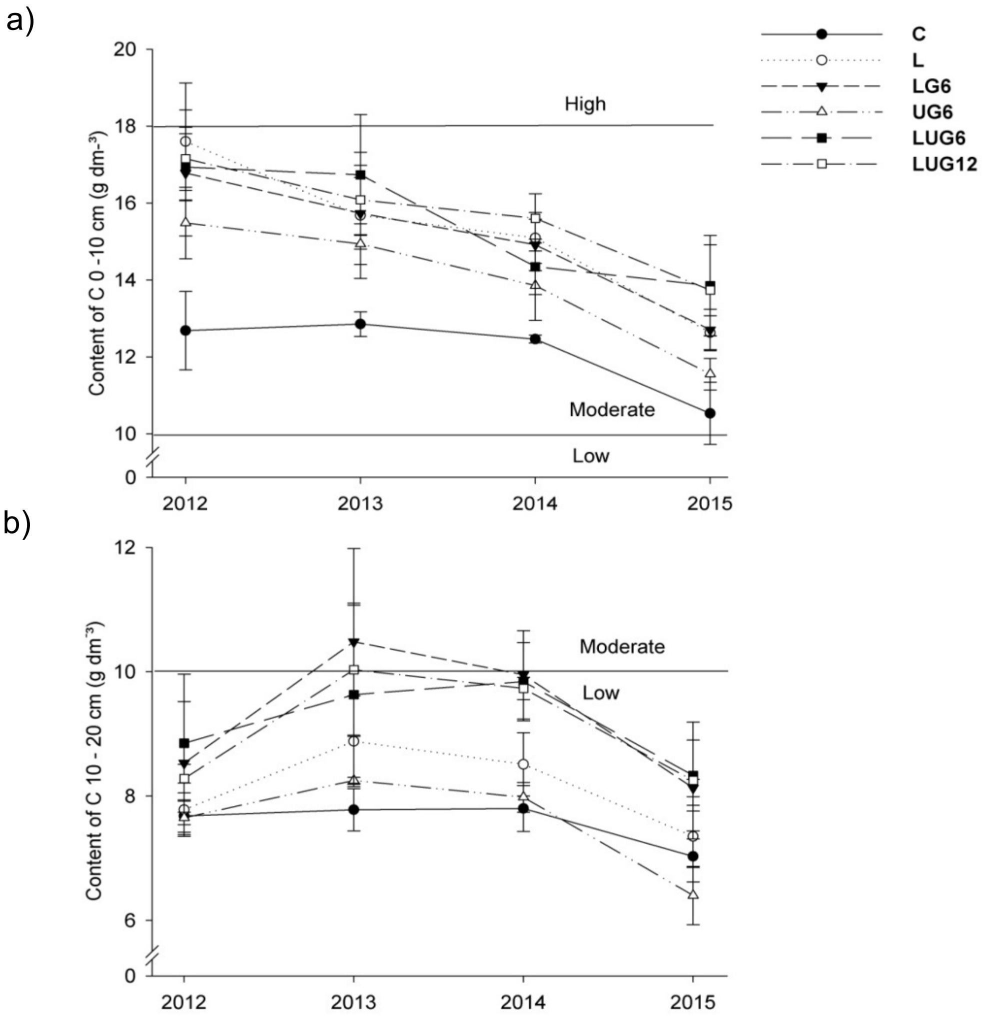

Figure 2.
Content of carbon in the soil, in the depth of 0 – 10 (a) and 10 – 20 (b) cm in 2012, 2013, 2014 and 2015. C= control ; L = leguminous; LG6 = leguminous and 6 Mg ha^{-1} of gypsum; UG6 = urea and 6 Mg ha^{-1} of gypsum; LUG6 = leguminous, urea and 6 Mg ha^{-1} of gypsum; LUG12 = leguminous, urea and 12 Mg ha^{-1} 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.

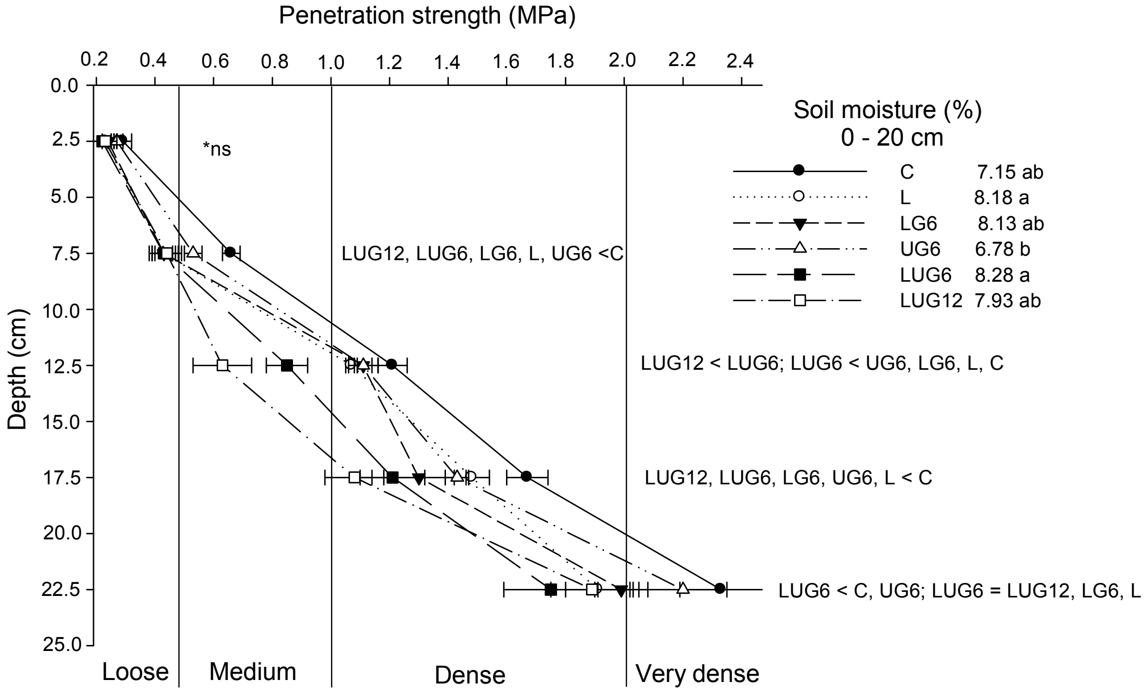

Figure 3.
Penetration strength after 4 days without rain and gravimetric soil moisture in 2015. C= control ; L = leguminous; LG6 = leguminous and 6 Mg ha^{-1} of gypsum; UG6 = urea and 6 Mg ha^{-1} of gypsum; LUG6 = leguminous, urea and 6 Mg ha^{-1} of gypsum; LUG12 = leguminous, urea and 12 Mg ha^{-1} 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.

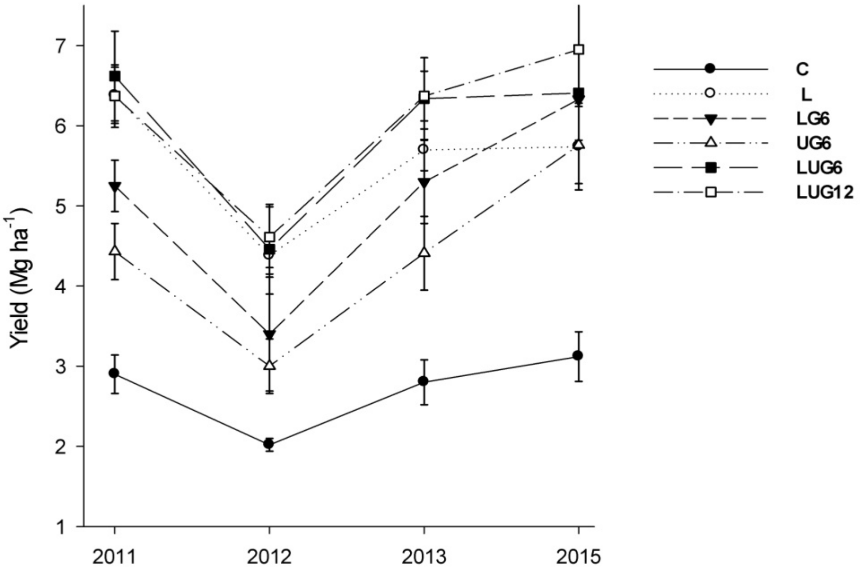

Figure 4.
Maize yield in the experimental area in 2011, 2012, 2013 and 2015. C= control ; L = leguminous; LG6 = leguminous and 6 Mg ha^{-1} of gypsum; UG6 = urea and 6 Mg ha^{-1} of gypsum; LUG6 = leguminous, urea and 6 Mg ha^{-1} of gypsum; LUG12 = leguminous, urea and 12 Mg ha^{-1} of gypsum. Bars show standard errors.

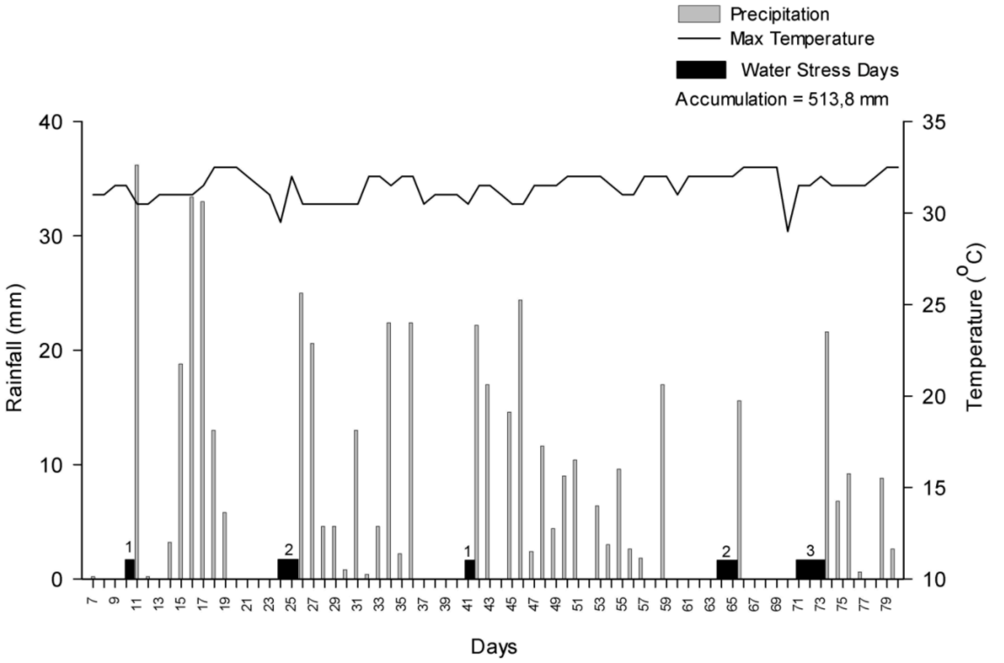

Figure 5.
Rainfall, maximum temperature (Max temperature) and water stress days in the experimental area during 6-80 days after sown of maize in 2012.

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.

	C	**U**	**L**	**LG6**	**UG6**	**LUG6**	**LUG12**
LAI (m^2 m^{-2})	2.45 b	2.58 b	3.06 a	3.03 a	3.04 a	3.08 a	3.29 a
NT (Kg ha^{-1})	34.69 c	57.98 c	76.38 b	69.43 b	75.45 b	103.16 a	94.28 a
NR (Kg ha^{-1})	8.38 c	13.68 c	38.67 b	37.65 b	27.89 b	56.41 a	52.35 a
NPT (Kg ha^{-1})	27.24 c	28.00 c	41.19 ab	50.46 a	37.19 b	42.20 a	45.16 a
NG (Kg ha^{-1})	39.43 d	52.18 d	72.28 bc	88.35 ab	70.14 c	88.61 ab	94.50 a
TN (Kg ha^{-1})	61.93 c	85.98 bc	117.57 ab	119.89 a	112.64 ab	145.36 a	139.44 a
DM (Mg ha^{-1})	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^{-1} of gypsum; UG6 = urea and 6 Mg ha^{-1} of gypsum; LUG6 = leguminous, urea and 6 Mg ha^{-1} of gypsum; LUG12 = leguminous, urea and 12 Mg ha^{-1} 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^{-1}, weight of 100 grains and weight of grains in the experimental area, 2015.

	C	U	L	LG6	UG6	LUG6	LUG12
Weight of ear (g)	118.48 c	162.10 b	188.71 ab	183.85 ab	190.61 ab	198.26 a	199.40 a
Number of grains ear $^{-1}$	447 c	555 b	619 ab	619 ab	618 ab	624 a	628 a
Weight of 100 grains (g)	26.24 b	28.99 ab	30.50 a	29.65 a	30.84 a	31.96 a	31.52 a
Weight of grains (Mg ha^{-1})	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^{-1} of gypsum; UG6 = urea and 6 Mg ha^{-1} of gypsum; LUG6 = leguminous, urea and 6 Mg ha^{-1} of gypsum; LUG12 = leguminous, urea and 12 Mg ha^{-1} 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^{-1}. 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^{2+}, therefore interactions between calcium organic macromolecules result in the formation of strong bonds involving

Ca^{2+}-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 stated 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^{2+} 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 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^{-1}) and U (28.00 Kg ha^{-1}) 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.

Acknowledgements

We are grateful to CAPES and FAPEMA for financial support.

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.

Anikwe, M.A.N., Eze, J.C., Ibudialo, A.N., 2016. Influence of lime and gypsum application on soil properties and yield of cassava (*Manihot esculenta Crantz.*) in a degraded Ultisol in Agbani, Enugu Southeastern Nigeria. Soil and Tillage Research.158, 32–38.

Badorreck, A., Krümmelbein, J., Raab, T., 2015. Long-term effects of deep soil loosening on root distribution and soil physical parameters in compacted lignite mine soils. Geophysical Research Abstracts.17, EGU2015-14990.

Benjamin, J.G., Nielsen, D.C., Vigil, M.F., 2003. Quantifying effects of soil conditions on plant growth and crop production. Geoderma.116,137-148.

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

Borrel, A.K., Hammer, G.L., Henzell, R.G., 2000. Does maintaining green leaf area in sorghum improve yield under drought? II. Dry matter production and yield. Crop Science. 40, 1037–1048.

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 and Tillage Research. 68, 49-57.

Carrizo, M. E., Alesso, C. A., Cosentino, Diego., Imhoff, Silvia., 2015. Aggregation agents and structural stability in soils with different texture and organic carbon contents. Scientia Agricola.72, 75-82.

Christensen, B.T., 2000. Organic matter in soil - structure, function and turnover. Plant Production. 95.

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

Daniells, I.G., 2012. Cohesive soils: a review. Soil Research. 50, 349–359.

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.

Denmead, O.T., Shaw, R.H., 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agronomy Journal. 52, 272–274.

Drinkwater, L.E., Snapp, S.S., 2007. Nutrients in agroecosystems: rethinking the management paradigm. Advances in Agronomy. 92, 163–186.

Garnett, T., Conn, V., Kaiser, BN., 2009. Root based approaches to improving nitrogen use efficiency in plants. Plant Cell Environ. 32, 1272–1283.

Hazelton, P., Murphy, B., 2007. Interpreting soil test results. What do all the numbers mean? CSIRO Publishing, Australia.

Heckman, J.R., 2006. Soil fertility test interpretation: phosphorus, potassium, magnesium and calcium. Fact Sheet FS719, Rutgers Cooperative Extension, New Jersey Agricultural Experimental Extension.

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

Masclaux-Daubresse, C., Daniel-Vedel, F., Dechorgnat, J., Chardon, F., Gaufichon, L., 2010. Nitrogen uptake, assimilation and remobilization in plants: challenges for sustainable and productive agriculture. Annals of Botany. 105, 1141–1157.

Mbah, E.U., Eke-Okoro, O., 2015. Relationship between some growth parameters, dry matter content and yield of some sweet potato genotypes grown under rainfed weathered ultisols in the humid tropics. Journal of Agronomy. 14, 121-129.

Montgomery, E.G., 1911. Correlation studies of corn. Annual Reports. 24, 108–159.

Moore, T.R., Turunen, J., 2004. Carbon accumulation and storage in mineral subsoil beneath peat. Soil Science Society of American Journal. 68, 690–696.

Moura, E. G., Oliveira, 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 Manage. 28, 368-375.

Moura, E.G., Marques, E.S., Silva, T.M.B., Piedade, A.R., Aguiar, A.C.F., 2014. Interactions among leguminous trees, crops and weeds in a no-till alley cropping system. International Journal of Plant Production. 8, 441-456.

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., Sena, V.G.L., Sousa, C.C.M., Silva, F.R., Coelho, M.J.A., Macedo, V.R.A., Aguiar, A.C.F., 2016. Enhancement of the rootability of a structurally fragile tropical soil using gypsum and leguminous residues to increase the maize yield. Soil Use and Management. 32.

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. 335, 363-371.

Moussadek, R., Mrabet, R., Dahan, R., Zouahri, A., El Mourid, M., Van Ranst, E., 2014. Tillage System Affects Soil Organic Carbon Storage and Quality in Central Morocco. Applied and Environmental Soil Science. 2014, Article ID 654796.

Mulumba, L.N., Lal, R., 2008. Mulching effects on selected soil physical properties. Soil and Tillage Research. 98, 106 – 111.

Oste, L.A., Temminghoff, E.J.M., Van Riemsdijk, W.H., 2002. Solid solution partitioning of organic matter in soils as influenced by an increase in pH or Ca concentration. Environmental Science and Technology. 36, 208–214.

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.

Sadras, V.O., Milroy, S.P., 1996. Soil – Water thresholds for the responses of leaf expansion and gas exchange: A review. Field Crops Research. 47, 253-266.

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.

Sivasankar, S., Rothstein, S., Oaks, A., 1997. Regulation of the accumulation and reduction of nitrate by nitrogen and carbon metabolites in maize seedlings. Plant Physiology. 114, 583–589.

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.

Tiessen, H., Moir, J.O., 1993. Total and organic carbon. In: Soil Sampling and Methods of Analysis, M.E. Carter, Ed. Lewis Publishers, Ann Arbor, MI. 187-200.

Whittinghill, K., Hobbie, A., Sarah, E., 2012. Effects of pH and calcium on soil organic matter dynamics in Alaskan tundra. Biogeochemistry. 111, 569–581.

Wieder, R.W., Cleveland, C.C., Townsend, A.R., 2009. Controls over leaf litter decomposition in wet tropical forests. Ecology. 90, 3333–3341.

Wong, M.T.F., Asseng, S., 2007. Yield and environmental benefits of ameliorating subsoil constraints under variable rainfall in a Mediterranean environment. Plant Soil. 297, 29-42.

Wuddivira, M.N., Camps-Roach, G., 2007. Effects of organic matter and calcium on soil structural stability. European Journal of Soil Science. 58, 722–727.

ANEXO

SOIL & TILLAGE RESEARCH

GUIDE FOR AUTHORS

INTRODUCTION

An international journal on research and development in soil tillage and field traffic, and their relationship with land use, crop production and the environment. Published in collaboration with the International Soil Tillage Research Organization (ISTRO).

This ISTRO-affiliated journal examines the physical, chemical and biological changes in the soil caused by tillage and field traffic. Manuscripts will be considered on aspects of soil science, physics, technology, mechanization and applied engineering for a sustainable balance among productivity, environmental quality and profitability. The following are examples of suitable topics within the scope of the journal of Soil and Tillage Research: The agricultural and biosystems engineering associated with tillage (including no-tillage, reduced-tillage and direct drilling), irrigation and drainage, crops and crop rotations, fertilization, rehabilitation of mine spoils and processes used to modify soils. Soil change effects on establishment and yield of crops, growth of plants and roots, structure and erosion of soil, cycling of carbon and nutrients, greenhouse gas emissions, leaching, runoff and other processes that affect environmental quality. Characterization or modeling of tillage and field traffic responses, soil, climate, or topographic effects, soil deformation processes, tillage tools, traction devices, energy requirements, economics, surface and subsurface water quality effects, tillage effects on weed, pest and disease control, and their interactions.

Types of paper

1. Original research papers (Regular Papers)

2. Review articles

3. Short Communications

4. Book reviews

Original research papers should report the results of original research. The material should not have been previously published elsewhere, except in a preliminary form.

Review articles should cover subjects falling within the scope of the journal which are of active current interest. They may be submitted or invited.

A Short Communication is a concise but complete description of a limited investigation, which will not be included in a later paper. Short Communications should be as completely documented, both by reference to the literature and description of the experimental procedures employed, as a regular paper. They should not occupy more than 6 printed pages (about 12 manuscript pages, including figures, tables and references).

Book Reviews will be included in the journal on a range of relevant books which are not more than 2 years old. Book reviews are solicited by the Editors-in-Chief. Please contact one of the Editors-in-Chief. E-mail contact details at:http://www.elsevier.com/wps/find/journaleditorialboard.cws_home/503318/editorialboard

BEFORE YOU BEGIN

Ethics in publishing

For information on Ethics in publishing and Ethical guidelines for journal publication see https://www.elsevier.com/publishingethics and https://www.elsevier.com/journal-authors/ethics.

Conflict of interest

All authors are requested to disclose any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work. See also https://www.elsevier.com/conflictsofinterest. Further information and an example of a Conflict of Interest form can be found at: http://service.elsevier.com/app/answers/detail/a_id/286/supporthub/publishing.

Submission declaration and verification

Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see https://www.elsevier.com/sharingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. To verify originality, your article may be checked by the originality detection service CrossCheck https://www.elsevier.com/editors/plagdetect.

Changes to authorship

Authors are expected to consider carefully the list and order of authors **before** submitting their manuscript and provide the definitive list of authors at the time of the original submission. Any addition, deletion or rearrangement of author names in the authorship list should be made only **before** the manuscript has been accepted and only if approved by the journal Editor. To request such a change, the Editor must receive the following from the **corresponding author**: (a) the reason for the change in author list and (b) written confirmation (e-mail, letter) from all authors that they agree with the addition, removal or rearrangement. In the case of addition or removal of authors, this includes confirmation from the author being added or removed.

Only in exceptional circumstances will the Editor consider the addition, deletion or rearrangement of authors **after** the manuscript has been accepted. While the Editor considers the request, publication of the manuscript will be suspended. If the manuscript has already been published in an online issue, any requests approved by the Editor will result in a corrigendum.

Article Transfer Service

This journal is part of our Article Transfer Service. This means that if the Editor feels your article is more suitable for another journal, you may be asked to consider transferring your article to the alternative journal of your choice. If you agree, your article will be transferred automatically on your behalf with no need to reformat. More information about this can be found here: http://www.elsevier.com/authors/article-transfer-service.

Copyright

Upon acceptance of an article, authors will be asked to complete a 'Journal Publishing Agreement' (for more information on this and copyright, see https://www.elsevier.com/copyright). An e-mail will be sent to the corresponding author confirming receipt of the manuscript together with a 'Journal Publishing Agreement' form or a link to the online version of this agreement.

Subscribers may reproduce tables of contents or prepare lists of articles including abstracts for internal circulation within their institutions. Permission of the Publisher is required for resale or distribution outside the institution and for all other derivative works, including compilations and translations (please consult https://www.elsevier.com/permissions). If excerpts from other copyrighted works are included, the author(s) must obtain written permission from the copyright owners and credit the source(s) in the article. Elsevier has preprinted forms for use by authors in these cases: please consult https://www.elsevier.com/permissions.

For open access articles: Upon acceptance of an article, authors will be asked to complete an 'Exclusive License Agreement' (for more information see https://www.elsevier.com/OAauthoragreement). Permitted third party reuse of open access articles is determined by the author's choice of user license (see https://www.elsevier.com/openaccesslicenses).

Author rights

As an author you (or your employer or institution) have certain rights to reuse your work. For more information see https://www.elsevier.com/copyright.

Role of the funding source

You are requested to identify who provided financial support for the conduct of the research and/or preparation of the article and to briefly describe the role of the sponsor(s), if any, in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication. If the funding source(s) had no such involvement then this should be stated.

Funding body agreements and policies

Elsevier has established a number of agreements with funding bodies which allow authors to comply with their funder's open access policies. Some authors may also be reimbursed for associated publication fees. To learn more about existing agreements please visit https://www.elsevier.com/fundingbodies.

Open access

This journal offers authors a choice in publishing their research:

Open access

- Articles are freely available to both subscribers and the wider public with permitted reuse

- An open access publication fee is payable by authors or on their behalf e.g. by their research funder or institution

Subscription

- Articles are made available to subscribers as well as developing countries and patient groups through our universal access programs (https://www.elsevier.com/access).
- No open access publication fee payable by authors.

Regardless of how you choose to publish your article, the journal will apply the same peer review criteria and acceptance standards.

For open access articles, permitted third party (re)use is defined by the following Creative Commons user licenses:

Creative Commons Attribution (CC BY)

Lets others distribute and copy the article, create extracts, abstracts, and other revised versions, adaptations or derivative works of or from an article (such as a translation), include in a collective work (such as an anthology), text or data mine the article, even for commercial purposes, as long as they credit the author(s), do not represent the author as endorsing their adaptation of the article, and do not modify the article in such a way as to damage the author's honor or reputation.

Creative Commons Attribution-NonCommercial-NoDerivs (CC BY-NC-ND)

For non-commercial purposes, lets others distribute and copy the article, and to include in a collective work (such as an anthology), as long as they credit the author(s) and provided they do not alter or modify the article.

The open access publication fee for this journal is **USD 2500**, excluding taxes. Learn more about Elsevier's pricing policy: http://www.elsevier.com/openaccesspricing.

Green open access

Authors can share their research in a variety of different ways and Elsevier has a number of green open access options available. We recommend authors see our green open access page for further information (http://elsevier.com/greenopenaccess). Authors can also self-archive their manuscripts immediately and enable public access from their institution's repository after an embargo period. This is the version that has been accepted for publication and which typically includes author-incorporated changes suggested during submission, peer review and in editor-author communications. Embargo period: For subscription articles, an appropriate amount of time is needed for journals to deliver value to subscribing customers before an article becomes freely available to the public. This is the embargo period and it begins from the date the article is formally published online in its final and fully citable form.

This journal has an embargo period of 24 months.

Language (usage and editing services)

Please write your text in good English (American or British usage is accepted, but not a mixture of these). Authors who feel their English language manuscript may require editing to eliminate possible grammatical or spelling errors and to conform to correct scientific English may wish to use the English Language Editing service available from Elsevier's WebShop (http://webshop.elsevier.com/languageediting/) or visit our customer support site (http://support.elsevier.com) for more information.

Submission

Authors be urged to only submit manuscripts that are ready and mature. Authors should not anticipate that reviewers would do authors jobs. Our online submission system guides you stepwise through the process of entering your article details and uploading your files. The system converts your article files to a single PDF file used in the peer-review process. Editable files (e.g., Word, LaTeX) are required to typeset your article for final publication. All correspondence, including notification of the Editor's decision and requests for revision, is sent by e-mail.

Submit your article

Please submit your article via http://ees.elsevier.com/still/

Referees

Please submit, with the manuscript, the names, addresses and e-mail addresses of five potential referees. The referees must not have a conflict of interest with any of the authors or the content of the manuscript. For this reason, do not submit referees who are part of your or your co-authors' institutions, or referees you or your co-authors have collaborated with in the past three years. Ideally referees from several different countries are invited. Potential referees should be experts in the field of your research, having published peer-reviewed papers on the subject. Note that the editor retains the sole right to decide whether or not the suggested reviewers are used.

PREPARATION

Use of word processing software

It is important that the file be saved in the native format of the word processor used. The text should be in single-column format. Keep the layout of the text as simple as possible. Most formatting codes will be removed and replaced on processing the article. In particular, do not use the word processor's options to justify text or to hyphenate words. However, do use bold face, italics, subscripts, superscripts etc. When preparing tables, if you are using a table grid, use only one grid for each individual table and not a grid for each row. If no grid is used, use tabs, not spaces, to align columns. The electronic text should be prepared in a way very similar to that of conventional manuscripts (see also the Guide to Publishing with Elsevier: http://www.elsevier.com/guidepublication). Note that source files of figures, tables and text graphics will be required whether or not you embed your figures in the text. See also the section on Electronic artwork.

To avoid unnecessary errors you are strongly advised to use the 'spell-check' and 'grammar-check' functions of your word processor.

Manuscripts should be prepared with numbered lines, with wide margins and double line spacing throughout, i.e. also for abstracts, footnotes and references. Every page of the manuscript, including the title page, references, tables, etc. should be numbered. However, in the text no reference should be made to page numbers; if necessary, one may refer to sections.

Article structure

Subdivision - numbered sections

Divide your article into clearly defined and numbered sections. Subsections should be numbered

1.1 (then 1.1.1, 1.1.2, ...), 1.2, etc. (the abstract is not included in section numbering). Use this numbering also for internal cross-referencing: do not just refer to 'the text'. Any subsection may be given a brief heading. Each heading should appear on its own separate line.

Introduction

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

Material and methods

Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described.

Results

Results should be clear and concise.

Discussion

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

Conclusions

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

Appendices

If there is more than one appendix, they should be identified as A, B, etc. Formulae and equations in appendices should be given separate numbering: Eq. (A.1), Eq. (A.2), etc.; in a subsequent appendix, Eq. (B.1) and so on. Similarly for tables and figures: Table A.1; Fig. A.1, etc.

Essential title page information

- ***Title.*** Concise and informative. Titles are often used in information-retrieval systems. Avoid abbreviations and formulae where possible.

- ***Author names and affiliations.*** Please clearly indicate the given name(s) and family name(s) of each author and check that all names are accurately spelled. Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower- case superscript letter immediately after the author's name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name and, if available, the e-mail address of each author.

- ***Corresponding author.*** Clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication. **Ensure that the e-mail address is given and that contact details are kept up to date by the corresponding author.**

- ***Present/permanent address.*** If an author has moved since the work described in the article was done, or was visiting at the time, a 'Present address' (or 'Permanent address') may be indicated as a footnote to that author's name. The address at which the author actually did the work must be retained as the main, affiliation address. Superscript Arabic numerals are used for such footnotes.

Abstract

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

Graphical abstract

Although a graphical abstract is optional, its use is encouraged as it draws more attention to the online article. The graphical abstract should summarize the contents of the article in a concise, pictorial form designed to capture the attention of a wide readership. Graphical abstracts should be submitted as a separate file in the online submission system. Image size: Please provide an image with a minimum of 531 × 1328 pixels (h × w) or proportionally more. The image should be readable at a size of 5 × 13 cm using a regular screen resolution of 96 dpi. Preferred file types: TIFF, EPS, PDF or MS Office files. See https://www.elsevier.com/graphicalabstracts for examples.

Authors can make use of Elsevier's Illustration and Enhancement service to ensure the best presentation of their images and in accordance with all technical requirements: Illustration Service.

Highlights

Highlights are mandatory for this journal. They consist of a short collection of bullet points that convey the core findings of the article and should be submitted in a separate editable file in the online submission system. Please use 'Highlights' in the file name and include 3 to 5 bullet points (maximum

85 characters, including spaces, per bullet point). See https://www.elsevier.com/highlights for examples.

Abbreviations

Define abbreviations that are not standard in this field in a footnote to be placed on the first page of the article. Such abbreviations that are unavoidable in the abstract must be defined at their first mention there, as well as in the footnote. Ensure consistency of abbreviations throughout the article.

Acknowledgements

Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on the title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, writing assistance or proof reading the article, etc.).

Nomenclature and units

Follow internationally accepted rules and conventions: use the international system of units (SI). If other units are mentioned, please give their equivalent in SI. Abbreviate units of measure only when used with numerals.

Authors and Editor(s) are, by general agreement, obliged to accept the rules governing biological nomenclature, as laid down in the *International Code of Botanical Nomenclature*, the *International Code of Nomenclature of Bacteria*, and the *International Code of Zoological Nomenclature*.

All biotica (crops, plants, insects, birds, mammals, etc.) should be identified by their scientific names when the English term is first used, with the exception of common domestic animals.

All biocides and other organic compounds must be identified by their Geneva names when first used in the text. Active ingredients of all formulations should be likewise identified.

For chemical nomenclature, the conventions of the *International Union of Pure and Applied Chemistry* and the official recommendations of the *IUPAC-IUB Combined Commission on Biochemical Nomenclature* should be followed.

Math formulae

Present simple formulae in the line of normal text where possible. In principle, variables are to be presented in italics.

Number consecutively any equations that have to be displayed separate from the text (if referred to explicitly in the text).

Subscripts and superscripts should be clear.

Greek letters and other non-Roman or handwritten symbols should be explained in the margin where they are first used. Take special care to show clearly the difference between zero (0) and the letter O, and between one (1) and the letter l.

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,

**P <0.01 and ***P <0.001.

In chemical formulae, valence of ions should be given as, e.g., Ca2+, not as Ca++.

Isotope numbers should precede the symbols, e.g., 18O.

Footnotes

Footnotes should be used sparingly. Number them consecutively throughout the article. Many word processors can build footnotes into the text, and this feature may be used. Otherwise, please indicate the position of footnotes in the text and list the footnotes themselves separately at the end of the article. Do not include footnotes in the Reference list.

Artwork

Electronic artwork General points

- Make sure you use uniform lettering and sizing of your original artwork.
- Embed the used fonts if the application provides that option.
- Aim to use the following fonts in your illustrations: Arial, Courier, Times New Roman, Symbol, or use fonts that look similar.
- Number the illustrations according to their sequence in the text.
- Use a logical naming convention for your artwork files.
- Provide captions to illustrations separately.
- Size the illustrations close to the desired dimensions of the published version.
- Submit each illustration as a separate file.

A detailed guide on electronic artwork is available on our website: https://www.elsevier.com/artworkinstructions.

You are urged to visit this site; some excerpts from the detailed information are given here.

Formats

If your electronic artwork is created in a Microsoft Office application (Word, PowerPoint, Excel) then please supply 'as is' in the native document format.

Regardless of the application used other than Microsoft Office, when your electronic artwork is finalized, please 'Save as' or convert the images to one of the following formats (note the resolution requirements for line drawings, halftones, and line/halftone combinations given below):

EPS (or PDF): Vector drawings, embed all used fonts.

TIFF (or JPEG): Color or grayscale photographs (halftones), keep to a minimum of 300 dpi.

TIFF (or JPEG): Bitmapped (pure black & white pixels) line drawings, keep to a minimum of 1000 dpi.

TIFF (or JPEG): Combinations bitmapped line/half-tone (color or grayscale), keep to a minimum of 500 dpi.

Please do not:

- Supply files that are optimized for screen use (e.g., GIF, BMP, PICT, WPG); these typically have a low number of pixels and limited set of colors;

- Supply files that are too low in resolution;

- Submit graphics that are disproportionately large for the content.

Color artwork

Please make sure that artwork files are in an acceptable format (TIFF (or JPEG), EPS (or PDF), or MS Office files) and with the correct resolution. If, together with your accepted article, you submit usable color figures then Elsevier will ensure, at no additional charge, that these figures will appear in color online (e.g., ScienceDirect and other sites) regardless of whether or not these illustrations are reproduced in color in the printed version. **For color reproduction in print, you**

will receive information regarding the costs from Elsevier after receipt of your accepted article. Please indicate your preference for color: in print or online only. For further information on the preparation of electronic artwork, please see https://www.elsevier.com/artworkinstructions.

Figure captions

Ensure that each illustration has a caption. Supply captions separately, not attached to the figure. A caption should comprise a brief title (**not** on the figure itself) and a description of the illustration. Keep text in the illustrations themselves to a minimum but explain all symbols and abbreviations used.

Tables

Please submit tables as editable text and not as images. Tables can be placed either next to the relevant text in the article, or on separate page(s) at the end. Number tables consecutively in accordance with their appearance in the text and place any table notes below the table body. Be sparing in the use of tables and ensure that the data presented in them do not duplicate results described elsewhere in the article. Please avoid using vertical rules.

References

Citation in text

Please ensure that every reference cited in the text is also present in the reference list (and vice versa). Any references cited in the abstract must be given in full. Unpublished results and personal communications are not recommended in the reference list, but may be mentioned in the text. If these references are included in the reference list they should follow the standard reference style of the journal and should include a substitution of the publication date with either 'Unpublished results' or 'Personal communication'. Citation of a reference as 'in press' implies that the item has been accepted for publication.

Web references

As a minimum, the full URL should be given and the date when the reference was last accessed. Any further information, if known (DOI, author names, dates, reference to a source publication, etc.), should also be given. Web references can be listed separately (e.g., after the reference list) under a different heading if desired, or can be included in the reference list.

References in a special issue

Please ensure that the words 'this issue' are added to any references in the list (and any citations in the text) to other articles in the same Special Issue.

Reference management software

Most Elsevier journals have their reference template available in many of the most popular reference management software products. These include all products that support Citation Style Language styles (http://citationstyles.org), such as Mendeley (http://www.mendeley.com/features/reference-manager) and Zotero (https://www.zotero.org/), as well as EndNote (http://endnote.com/downloads/styles). Using the word processor plug-ins from these products, authors only need to select the appropriate journal template when preparing their article, after which citations and bibliographies will be automatically formatted in the journal's style. If no template is yet available for this journal, please follow the format of the sample references and citations as shown in this Guide.

Users of Mendeley Desktop can easily install the reference style for this journal by clicking the following link:

http://open.mendeley.com/use-citation-style/soil-and-tillage-research

When preparing your manuscript, you will then be able to select this style using the Mendeley plug- ins for Microsoft Word or LibreOffice.

Reference style

Text: All citations in the text should refer to:

1. *Single author:* the author's name (without initials, unless there is ambiguity) and the year of publication;

2. *Two authors:* both authors' names and the year of publication;

3. *Three or more authors:* first author's name followed by 'et al.' and the year of publication. Citations may be made directly (or parenthetically). Groups of references should be listed first alphabetically, then chronologically.

Examples: 'as demonstrated (Allan, 2000a, 2000b, 1999; Allan and Jones, 1999). Kramer et al. (2010) have recently shown ....'

List: References should be arranged first alphabetically and then further sorted chronologically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters 'a', 'b', 'c', etc., placed after the year of publication.

Examples:

Reference to a journal publication:

Van der Geer, J., Hanraads, J.A.J., Lupton, R.A., 2010. The art of writing a scientific article. J. Sci. Commun. 163, 51–59.

Reference to a book:

Strunk Jr., W., White, E.B., 2000. The Elements of Style, fourth ed. Longman, New York. Reference to a chapter in an edited book:

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

Reference to a website:

Cancer Research UK, 1975. Cancer statistics reports for the UK. http://www.cancerresearchuk.org/ aboutcancer/statistics/cancerstatsreport/ (accessed 13.03.03).

Journal abbreviations source

Journal names should be abbreviated according to the List of Title Word Abbreviations: http://www.issn.org/services/online-services/access-to-the-ltwa/.

Video data

Elsevier accepts video material and animation sequences to support and enhance your scientific research. Authors who have video or animation files that they wish to submit with their article are strongly encouraged to include links to these within the body of the article. This can be done in the same way as a figure or table by referring to the video or animation content and noting in the body text where it should be placed. All submitted files should be properly labeled so that they directly relate to the video file's content. In order to ensure that your video or animation material is directly usable, please provide the files in one of our recommended file formats with a preferred maximum size of 150 MB. Video and animation files supplied will be published online in the electronic version of your article in Elsevier Web products, including ScienceDirect: http://www.sciencedirect.com. Please supply 'stills' with your files: you can choose any frame from the video or animation or make a separate image. These will be used instead of standard icons and will personalize the link to your video data. For more detailed instructions please visit our video instruction pages at https://www.elsevier.com/artworkinstructions. Note: since video and animation cannot be embedded in the print version of the journal, please provide text for both the electronic and the print version for the portions of the article that refer to this content.

AudioSlides

The journal encourages authors to create an AudioSlides presentation with their published article. AudioSlides are brief, webinar-style presentations that are shown next to the online article on ScienceDirect. This gives authors the opportunity to summarize their research in their own words and to help readers understand what the paper is about. More information and examples are available at https://www.elsevier.com/audioslides. Authors of this journal will automatically receive an invitation e-mail to create an AudioSlides presentation after acceptance of their paper.

Supplementary material

Supplementary material can support and enhance your scientific research. Supplementary files offer the author additional possibilities to publish supporting applications, high-resolution images, background datasets, sound clips and more. Please note that such items are published online exactly as they are submitted; there is no typesetting involved (supplementary data supplied as an Excel file or as a PowerPoint slide will appear as such online). Please submit the material together with the article and supply a concise and descriptive caption for each file. If you wish to make any changes to supplementary data during any stage of the process, then please make sure to provide an updated file, and do not annotate any corrections on a previous version. Please also make sure to switch off the 'Track Changes' option in any Microsoft Office files as these will appear in the published supplementary file(s). For more detailed instructions please visit our artwork instruction pages at https://www.elsevier.com/artworkinstructions.

Database linking

Elsevier encourages authors to connect articles with external databases, giving readers access to relevant databases that help to build a better understanding of the described research. Please refer to relevant database identifiers using the following format in your article: Database: xxxx (e.g., TAIR: AT1G01020; CCDC: 734053; PDB: 1XFN). See https://www.elsevier.com/databaselinking for more information and a full list of supported databases.

Google Maps and KML files

KML (Keyhole Markup Language) files (optional): You can enrich your online articles by providing KML or KMZ files which will be visualized using Google maps. The KML or KMZ files can be uploaded in our online submission system. KML is an XML schema for expressing geographic annotation and visualization within Internet-based Earth browsers. Elsevier will generate Google Maps from the submitted KML files and include these in the article when published online. Submitted KML files will also be available for downloading from your online article on ScienceDirect. For more information see https://www.elsevier.com/googlemaps.

Interactive plots

This journal enables you to show an Interactive Plot with your article by simply submitting a data file. For instructions please go to https://www.elsevier.com/interactiveplots.

Submission checklist

The following list will be useful during the final checking of an article prior to sending it to the journal for review. Please consult this Guide for Authors for further details of any item.

Ensure that the following items are present:

One author has been designated as the corresponding author with contact details:

- E-mail address
- Full postal address

All necessary files have been uploaded, and contain:

- Keywords
- All figure captions
- All tables (including title, description, footnotes) Further

considerations

- Manuscript has been 'spell-checked' and 'grammar-checked'
- References are in the correct format for this journal
- All references mentioned in the Reference list are cited in the text, and vice versa
- Permission has been obtained for use of copyrighted material from other sources (including the Internet)

Printed version of figures (if applicable) in color or black-and-white

- Indicate clearly whether or not color or black-and-white in print is required.

For any further information please visit our customer support site at http://support.elsevier.com.

AFTER ACCEPTANCE

Use of the Digital Object Identifier

The Digital Object Identifier (DOI) may be used to cite and link to electronic documents. The DOI consists of a unique alpha-numeric character string which is assigned to a document by the publisher upon the initial electronic publication. The assigned DOI never changes. Therefore, it is an ideal medium for citing a document, particularly 'Articles in press' because they have not yet received their full bibliographic information. Example of a correctly given DOI (in URL format; here an article in the journal *Physics Letters B*):

http://dx.doi.org/10.1016/j.physletb.2010.09.059

When you use a DOI to create links to documents on the web, the DOIs are guaranteed never to change.

Online proof correction

Corresponding authors will receive an e-mail with a link to our online proofing system, allowing annotation and correction of proofs online. The environment is similar to MS Word: in addition to editing text, you can also comment on figures/tables and answer questions from the Copy Editor. Web-based proofing provides a faster and less error-prone process by allowing you to directly type your corrections, eliminating the potential introduction of errors.

If preferred, you can still choose to annotate and upload your edits on the PDF version. All instructions for proofing will be given in the e-mail we send to authors, including alternative methods to the online version and PDF.

We will do everything possible to get your article published quickly and accurately. Please use this proof only for checking the typesetting, editing, completeness and correctness of the text, tables and figures. Significant changes to the article as accepted for publication will only be considered at this stage with permission from the Editor. It is important to ensure that all corrections are sent back to us in one communication. Please check carefully before replying, as inclusion of any subsequent corrections cannot be guaranteed. Proofreading is solely your responsibility.

Offprints

The corresponding author, at no cost, will be provided with a personalized link providing 50 days free access to the final published version of the article on ScienceDirect. This link can also be used for sharing via email and social networks. For an extra charge, paper offprints can be ordered via the offprint order form which is sent once the article is accepted for publication. Both corresponding and co-authors may order offprints at any time via Elsevier's WebShop (http://webshop.elsevier.com/myarticleservices/offprints). Authors requiring printed copies of multiple articles may use Elsevier WebShop's 'Create Your Own Book' service to collate multiple articles within a single cover (http://webshop.elsevier.com/myarticleservices/booklets).