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Fábio Henrique Gebert

ERVILHACA PELUDA (*Vicia villosa* Roth) ASSOCIADA A FERTILIZAÇÃO NITROGENADA VISANDO A HOMOGENEIZAÇÃO DA PRODUTIVIDADE DO MILHO DAS ZONAS DE MANEJO

Santa Maria, RS
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Dissertação apresentada ao Programa de Pós-Graduação em Agricultura de Precisão, área de concentração em Manejo Específico de Solo e Planta, da Universidade Federal de Santa Maria (UFSM - RS), como requisito parcial para obtenção do Título de **Mestre em Agricultura de Precisão.**

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RESUMO

ERVILHACA PELUDA (*Vicia villosa* Roth) ASSOCIADA A FERTILIZAÇÃO NITROGENADA VISANDO A HOMOGENEIZAÇÃO DA PRODUTIVIDADE DO MILHO DAS ZONAS DE MANEJO

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As diferentes produtividades obeservadas em cada zona de manejo geralmente estão atreladas à características intrínsecas do solo e ao relevo encontrado em cada talhão. O milho é uma importante cultura de interesse econômico que apresenta alta resposta em produtividade a adubação nitrogenada e ao seu ambiente de crescimento. Já as plantas de cobertura leguminosas como a ervilhaca peluda, pode contribuir com a minimização dos efeitos nocivos desses fatores e auxiliar em produtividades mais homogêneas dentro das zonas de manejo através da melhoria dos ambientes de cultivo e da fixação biológica de nitrogênio. Dessa maneira o trabalho buscou investigar a contribuição em produtividade de milho entregue pela presença da ervilhaca peluda associada, ou não, a adubação nitrogenada mineral em diferentes zonas de manejo. A pesquisa foi realizada em duas áreas comerciais localizadas na cidade de carazinho, sul do Brasil com Latossolo Vermelho Distrófico típico de textura argilosa. As zonas de manejo foram delimitadas através dos mapas de altimetria, declividade, condutivida elétrica aparente do solo em duas profundidades (0-30 cm e 0-90 cm) e a produtividade do milho em ano anterior. O desenho experimental foi um bloco ao acaso com três repetições localizadas em cada zona de manejo e os tratamendos consistiram em 5 taxas de N (0, 60, 120, 180, 240 kg ha^{-1}) com e sem ervilhaca peluda nas 3 zonas avaliadas. Não foram observadas interações entre os três fatores para as variáveis de recuperação aparente de nitrogênio, produtividade de milho e eficiência da recuperação do nitrogênio. Porém todas as interações duplas se mostraram significativas ($p>0.05$). Aumento do nitrogênio recuperado foi de 23, 27 e 20% para as zonas de baixa, média e alta produtividade, respectivamente para o primeiro experimento e 29, 26 e 17% para as zonas de baixa, média e alta produtividade no segundo experimento. Assim, a ervilhaca peluda contribuiu em todos as zonas de manejo, porém os ambientes de baixa e média produtividade foram mais favorecidos pela presença da cultura de cobertura, provavelmente explicado pela presença de elementos topográficos menos favoráveis para o desenvolvimento da cultura e da recuperação do nitrogênio aplicado em cobertura. A quantidade de nitrogênio aparente deixada pela cultura da ervilhaca peluda foi de 64 kg N ha^{-1} para o primeiro experimento e 54 kg N ha^{-}

^{1} para o segundo experimento. Sendo que diferenças de produtividade não foram encontradas após a utilização de 120 kg N ha^{-1} para o primeiro experimento e 180 kg N ha^{-1} para o segundo experimento.

Palavras-chave: Agricultura de Precisão. Eficiência de Recuperação de Nitrogênio. Cultura de cobertura de inverno.

ABSTRACT

HAIRY VETCH WINTER COVER CROP (*Vicia villosa* Roth) ASSOCIATED WITH NITROGEN FERTILIZATION AIMING TO HOMOGENIZED CORN GROWN IN MANAGEMENT ZONES

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The different productivities in each management zone are usually linked to the intrinsic characteristics of the soil and landscape found in each field. Corn is an important crop of economic interest that presents a high productivity response to nitrogen fertilization and growing environment. On the other hand, legume cover crops such as hairy vetch can contribute with the minimization of the greasy effects of these factors and help to reach more homogenous productivities within the management zones through the improvement of cultivation environments and biological nitrogen fixation. In this way the work due to investigate the contribution in yield of maize delivered by the presence of hairy vetch associated with, or not, mineral nitrogen fertilization in different management zones. The research was carried out in two commercial areas located in the city of carazinho, southern Brazil with Typic Hapludox Soil. The management zones were delineated using one yield map from previous year, soil apparent electric conductivity from two depths (0-30 cm and 0-90 cm), terrain elevation and slope. The experimental design was a complete randomized block with three repetitions located within each MZ and the treatments consist of five N rates (0, 60, 120, 180, 240 kg ha^{-1}) with and without hairy vetch (HV) in a tree MZ. No interactions were observed between the three factors for the variables for apparent nitrogen recovery, maize productivity and nitrogen reduction efficiency. However, all double interactions were significant ($p>0.05$). Nitrogen recovery was 23, 27 and 20% for the low, medium and high yielding areas, respectively for the first experiment and 29, 26 and 17% for the low, medium and high productivity zones in the second experiment. Thus, hairy vetch contributed to all management areas, but low and medium productivity environments were more favored by the presence of cover crop, probably explained by the presence of less favorable topographic elements for crop development and nitrogen recovery applied in coverage. The amount of apparent nitrogen fixed by hairy vetch culture was 64 kg N ha^{-1} for the first experiment and 54 kg N ha^{-1} for the second experiment. Moreover, since productivity differences were not found after the use of 120 kg N ha^{-1} for the first experiment and 180 kg N ha^{-1} for the second experiment.

Keywords: Precision Agriculture. Nitrogen Recovery Efficiency. Winter Cover Crop.

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APPENDICES

LISTA DE ABREVIATURAS E SIGLAS

σ^2	Desvio Padrão
°C	Graus Celsius
AIC	Critérios de Akaike
AONR	Taxa de máxima eficiência técnica.
C / N	Relação Carbono/Nitrogênio
EC	Condutividade Elétrica
ECa	Condutividade elétrica do solo aparente
Exp	Expodencial
FPI	Índice de desempenho de Fuzzi
Gau	Gaussiano
Ha	Hectares
HYZ	Zona de alta produtividade
K2O	Dióxido de Potássio
Kg	Quilograma
LSD	Menor diferença significativa
LYZ	Zona de baixa produtividade
m2	Métro Quadrado
Max	Máximo
Min	Mínimo
MLM	Modelos lineares mistos
mm	milímetros
mS m^{-1}	Milisiemens por metro
MYZ	Zona de média produtividade
N	Nitrogênio
NCE	Entropia de Classificação Normalizada
P2O5	Pentóxido de fósforo
PC	Componente principal
R^2	Coeficiente de Determinação
RB	Blocos aleatórios
SPD	Sistema Plantio Direto
Sph	Esférico
VT	Estádio de pendoamento
ZM	Zonas de Manejo

SUMÁRIO

1 INTRODUÇÃO GERAL

O Brasil se destaca a cada ano pelos elevados índices de produtividade alcançados nas lavouras. O rápido e contínuo avanço da agricultura de precisão nos possibilitou trabalhar com enormes bancos de dados, buscando explorar e detalhar áreas como um todo. Praticamente toda e qualquer informação pode ser obtida e georreferenciada dentro dos limites de importância, possibilitando a geração de zonas de manejo a partir de atributos intrínsecos do solo, a fim de definir estratégias de manejo localizadas em função dos atributos que limitam elevar as atuais produtividades encontradas.

Há tempos o modelo de produção de grãos no Sul do Brasil vem se resumindo no cultivo de soja (*Glycine max*) e milho (*Zea mays*) durante a safra de verão, e trigo (*Triticum* spp.) no período de inverno. Porém, seu intenso uso, quando mal manejado, provoca a diminuição na fertilidade natural do solo, susceptibilidade à erosão e deficiência na ciclagem de nutrientes.

A baixa expressão econômica encontrada nos cereais de inverno, associada aos possíveis riscos ambientais, oportunizou a implantação de outras espécies durante a entressafra, visando um aprimoramento na qualidade do solo que diminua os efeitos nocivos do sistema. Assim, diversas espécies vegetais passaram a ser utilizadas como culturas de entressafra (cultivadas no outono/ inverno) com o objetivo de elevar a capacidade produtiva do solo.

Ao contrário das gramíneas (Poaceae), as espécies de leguminosas (Fabaceae), caracterizam-se pela baixa relação C:N dos resíduos e a fixação de N atmosférico através da simbiose com bactérias específicas, contribuindo em prol do balanço de N do solo. Deste modo, sua rápida decomposição (GIACOMINI et al., 2003) libera cerca de 60% do N acumulado da parte aérea durante os primeiros 30 dias posteriores ao seu manejo (AMADO et al., 1999; AITA et al., 2001; AITA; GIACOMINI, 2003).

Sangoi et al. (1999) relata desvantagens no uso de gramíneas de inverno, pois durante o processo de decomposição, a biomassa microbiana ao imobilizar o N, diminui a sua disponibilidade, podendo causar a deficiência de N e redução da produtividade do milho. Já Amado et al. (2003) e Sisti et al. (2004), mencionam que o cultivo das leguminosas demonstraram ser uma alternativa promissora na suplementação de N para cultivos em sucessão. A cultura da ervilhaca (*Vicia* spp.*)* enquadra-se como uma ótima alternativa de culturas antecessoras para gramíneas, que por natureza, tem alta influência do nitrogênio em seu rendimento (AMADO et al., 2002).

Assim, vários são os trabalhos que visam estabelecer a manifestação dos efeitos benéficos desses cultivos na entressafra, porém escassos aqueles que quantifiquem a contribuição desse manejo em zonas com diferentes potenciais produtivos dentro de um mesmo talhão.

1.1 HIPÓTESES

A adubação nitrogenada mineral isolada ou combinada com o cultivo da ervilhaca peluda pode anular ou minimizar os diferentes potenciais produtivos encontrados entre as zonas de manejo de um mesmo talhão.

1.2 OBJETIVOS

1.2.1 Objetivo geral

Avaliar o manejo integrado entre a fertilização nitrogenada mineral e as plantas de cobertura em resposta ao propósito de reduzir ou anular o efeito das zonas de manejo na produtividade do milho.

1.2.2 Objetivos específicos

Quantificar ganhos à curto prazo para a cultura do milho ofertados pela presença da ervilhaca dentro de cada zona de manejo.

Estimar a equivalência de nitrogênio advinda da ervilhaca peluda antecedendo a cultura do milho.

Estimar a contribuição da ervilhaca peluda em reduzir o efeito de zonas de manejo sobre a produtividade da cultura do milho.

2 REFERENCIAL TEÓRICO

2.1 ZONAS DE MANEJO

A agricultura de precisão auxilia o produtor na escolha das melhores estratégias de manejo a serem adotadas no intuito de obter elevadas produtividades. A mesma ainda reconhece a existência de variabilidade em uma mesma área, permitindo a identificação de fatores limitantes a produtividade de cada local, e assim, propor alternativas de manejo diferenciadas de acordo com as necessidades de cada zona de manejo (PES et al., 2006).

As zonas de manejo são caracterizadas como sendo áreas de um talhão com semelhante produtividade potencial, mesma eficiência do uso de insumos e semelhantes risco de impacto ambiental (LUCHIARI JUNIOR et al., 2000). As mesmas ainda são caracterizadas através do agrupamento de informações (mapas) de diferentes atributos que apresentem homogeneidade e o mesmo desempenho vegetal em uma determinada área para que sejam realizados manejos mais adequados paras as características de cada local. Segundo Luchiari Junior et al. (2001), a divisão de uma área em subáreas homogêneas pode ser eficiente para definir a dinâmica de uma lavoura e a aplicação localizada de insumos, garantindo que a cultura expresse o seu maior potencial produtivo em cada delimitação de zona.

A fim de orientar a delimitação das zonas de manejo e locais para amostragens de interesse, podem ser utilizados critérios baseados em: características topográficas da área, atributos do solo, mapas de produtividade, mapas de condutividade elétrica, histórico da área, além de critérios conjugados (VILENA et al., 2010). Segundo Li et al. (2007), informações referentes ao rendimento de culturas representam a melhor forma de diagnosticar as variações presentes no campo, sendo importante basear em informações espaciais que são estáveis ou previsíveis ao longo do tempo para a definição de zonas de manejo, estabelecendo relações espaciais associadas a características do solo.

Segundo Corá et al. (2004), a investigação da variabilidade espacial de atributos químicos e teor de argila da camada superficial e subsuperficial dos solos proporcionou a visualização e definição de zonas homogêneas de manejo, o que permite a adoção do sistema de agricultura de precisão, com a utilização de um manejo mais eficiente e econômico da cultura.

2.2 BENEFÍCIOS DO USO DE PLANTAS DE COBERTURA EM SISTEMA PLANTIO DIRETO

Considerada uma das premissas do Sistema Plantio Direto (SPD), a rotação de cultura e a diversificação de espécies de cobertura de solo, principalmente no período do inverno, se deve ao propósito de proteger o solo e melhorar suas características físicas, químicas e biológicas para a cultura subseqüente. O uso de culturas de cobertura previne a perda de nutrientes através da lixiviação (DABNEY et al., 2001), aumenta as entradas de carbono (C) no solo (MOORE et al., 2014) e tem potencial para elevar a diversidade biológica (TILLMAN et al., 2004), contribuindo na melhoria da fertilidade e qualidade do solo e posterior aumento do rendimento da seguinte safra comercial (SANTI et al., 2003).

O uso de culturas de cobertura no inverno tem se mostrado eficiente na prevenção do processo erosivo do solo (KASPAR et al., 2001). Além disso, Truman et al. (2003) verificaram que a biomassa aérea de culturas de cobertura pode reduzir as perdas de água do solo tanto pelos processos evaporativos como pelo escoamento superficial. Já quanto a biomassa da raiz de culturas de cobertura, Villamil et al. (2006) observaram melhoria na agregação do solo, na distribuição do tamanho dos poros e da água disponível para o cultivo em sucessão.

Embora promovam diversos benefícios agronômicos, as culturas de cobertura também podem promover malefícios a cultura em sucessão, como: redução do estande de plantas devido a interferência que os resíduos vegetais de cobertura causam sobre os equipamentos agrícolas, o que acarreta um sulco de sementes incompleto, impedindo um adequado contato entre a semente e o solo (ECKERT, 2013; KASPAR; BAKKER, 2015), e a redução da disponibilidade de N inorgânica devido a absorção direta durante o crescimento das plantas de cobertura ou devido a imobilização de N durante a decomposição desses resíduos vegetais (KASPAR; BAKKER, 2015).

A relação C/N de culturas utilizadas nos sistemas de rotação reflete diretamente a liberação de nitrogênio para o solo, sendo a decomposição inversamente proporcional à relação C/N. Segundo Sá (1993) valores referentes a relação C/N abaixo de 23 favorecem a mineralização de resíduos orgânicos e valores acima de 24 favorecem a imobilização do nitrogênio pelos microorganismos do solo. Já, segundo os autores Moreira e Siqueira (2006) e Silva et al. (2008), os resíduos com uma relação C/N inferior a 20 são mais facilmente colonizados pela população microbiana devido a maior disponibilidade de nitrogênio.

Assim, uma das vantagens encontradas nas espécies leguminosas de inverno, é a capacidade de fixar N_2 atmosférico através da simbiose com bactérias específicas (GILLER; WILSON, 1993), contribuindo positivamente para o balanço de N no solo. Estimativas indicam que 46 kg de N são acumulados por tonelada de massa seca de parte aérea da ervilhaca comum (*Vicia sativa*) e que a contribuição média de N da ervilhaca é de l20 kg ha^{-1} variando de 50 a 200 kg ha^{-1} (BOLLIGER et al., 2006). Por fim, o uso da ervilhaca como cultura de cobertura, além de entregar vantagem semelhantes as demais culturas de cobertura, ainda fornece elevadas quantidades de N para culturas, como o milho em sucessão por exemplo. Essa prática pode levar a substituição parcial (AITA et al., 1994) ou total (DA ROS; AITA, 1996) do fertilizante mineral, motivo pelo qual é considerada um adubo verde.

Por apresentar menor teor de lignina, os restos culturais da ervilhaca peluda (*Vicia villosa* Roth) podem ser rapidamente degradados, proporcionando uma rápida liberação de nutrientes, podendo os nutrientes presentes nos restos culturais serem liberados nos primeiros

30 dias após a deposição na superfície do solo (AITA; GIACOMINI, 2003; DONEDA et al., 2012). A ervilhaca apresenta relação C/N em torno de 11 (FERREIRA et al., 2014), 13,5 (HEINRICHS et al., 2001) e 19 (SÁ, 1993), o que aumenta a taxa de decomposição desta leguminosa, evitando a imobilização do N no solo, oferecendo porém, uma menor proteção do solo deixado pelos restos culturais durante o ciclo da cultura posterior. Ainda, segundo Chaves et al. (2004), com o aumento da mineralização dos resíduos orgânicos, conseqüentemente haverá menor matéria seca residual no solo.

Devido a elevada e rápida disponibilidade de N deixada pela decomposição dos resíduas das leguminosas, recomenda-se o uso de leguminosas antecedendo a cultura de milho como fonte de suplementação de N na produção de milho. Marcillo e Miguez (2017) encontraram com o uso de leguminosas como culturas de cobertura no inverno um incremento na produtividade de milho em sucessão, entre 30% a 33% no uso de baixas taxas de adubos nitrogenados ou na mudança do sistema de preparo do solo do preparo convencional para plantio direto.

Em estudo desenvolvido por Silva et al. (2006) analisando culturas antecessoras e adubação nitrogenada na cultura do milho, em SPD, os autores concluíram que a cultura antecessora tem efeito diferenciado sobre as características agronômicas de milho cultivado no SPD. Segundo os autores, a indicação da quantidade de adubo nitrogenado a ser aplicado deve levar em consideração a cultura antecessora, uma vez que: o milho cultivado sobre ervilhaca peluda não apresentou respostas à adubação nitrogenada, sobre nabo forrageiro apresenta respostas até 50 kg ha^{-1} de N e, sobre aveia preta, apresenta respostas à adubação nitrogenada até a dose de 150 kg ha^{-1}. No mesmo estudo, na ausência de adubação nitrogenada as maiores produtividades de milho foram obtidas quando a cultura antecessora foi a ervilhaca peluda ou o nabo forrageiro e as menores, quando a cultura antecessora foi aveia preta.

Avaliando o efeito das culturas antecessoras, doses e fontes de nitrogênio nas características agronômicas do milho, no SPD, Lourente et al. (2007) concluíram que as culturas antecessoras (aveia preta, trigo, nabo forrageiro e ervilhaca peluda) influenciaram a produtividade, massa de 1000 grãos e teor de nitrogênio foliar do milho. Ao analisar diferentes coberturas de inverno utilizadas em sucessão ao milho, Gonçalves e Ceretta (1999) observaram que no verão, a ervilhaca situou-se entre os tratamentos que mantiveram maior quantidade de matéria seca de resíduos vegetais acumulados na superfície do solo (6400 kg ha^{-1}).

Ao comparar o efeito do uso de leguminosas, Amado et al. (1999) concluíram que o efeito imediato proporcionou incremento de 45,6% no rendimento do milho, enquanto que o efeito residual proporcionou apenas 19%. Os sistemas de produção de milho com a inclusão de adubos verdes proporcionaram elevada cobertura e foram efetivos no controle da erosão, reduzindo as perdas de solo, água e matéria orgânica (DEBARBA; AMADO, 1997).

A complementação de fertilizantes nitrogenados se tornou uma prática corriqueira uma vez que a quantidade naturalmente disponível no solo é insuficiente para suprir a demanda por N nas culturas. Embora reflita nos custos de produção, essa complementação se faz necessário para a obtenção de altas produtividades em culturas responsivas a esse fertilizante, como é o exemplo do milho. Nesse sentido, a utilização de culturas antecessoras com capacidade de recuperar os teores de matéria orgânica do solo e/ou com potencial de fixação biológica do N é de grande importância para o acúmulo de resíduos culturais em SPD aliada a práticas de manejo sustentáveis e de efeito benéfico ao meio ambiente. Devido a maior dificuldade na aquisição de sementes e na instalação do cultivo em relação às gramíneas, por terem desenvolvimento inicial lento e pela rápida decomposição de seus resíduos (SÁ, 1996), o cultivo de leguminosas antecedendo ao milho ainda é reduzido. No entanto, essa combinação de sucessão deve ser melhor estudada uma vez que os talhões apresentam diferentes potenciais produtivos.

3 MATERIAS E MÉTODOS

O presente estudo foi conduzido no município de Carazinho, (RS), na propriedade do Sr. Rogério Pacheco, localizado nas coordenadas geográficas, latitude 28º 17'S, e longitude 52º 47'O, com altitude média de 595m. O solo predominante é classificado com Latossolo Vermelho Distrófico típico com textura argilosa (EMBRAPA, 2006). O clima predominante é caracterizado como subtropical úmido (Cfa) com temperatura média de 16ºC e precipitação normal de 2020mm (KÖPPEN, 1948).

Após o levantamento dos atributos físicos e químicos da área, associados aos dados de elevação e produtividade ofertado pelo monitor de colheita e condutividade elétrica, definiram-se as zonas de manejo e a alocação das parcelas. Para o híbrido de milho utilizado na sucessão da ervilhaca optou-se pelo P1630H, com população de 64.000 plantas ha^{-1}.

O experimento foi composto por 2 variáveis qualitativas: presença de ervilhaca e zonas de manejo, e uma terceira variável quantitativa: doses progressivas de N (0, 60, 120, 180 e 240 Kg ha^{-1}), aplicadas no estádio fenológico V3-V4.

Para a avaliação da cultura do milho, foi realizado a coleta de tecido durante o estádio fenológico R1 (Espigamento), a fim de estimar a massa seca e a quantidade de N absorvido. Os dados de componente de rendimento de grãos e produtividade foram coletados de forma manual no centro de cada parcela (1 m²) e os pesos posteriormente corrigidos para 13% de umidade.

4 ARTIGO I - HAIRY VETCH/CORN CROPPING SYSTEM AIMING TO REDUCE THE MANAGEMENT ZONES EFFECT

ABSTRACT

The spatial variability of the different soil and landscape determine soil nitrogen (N) supply and crop response to N fertilizer between and within field. The hairy vetch cover crop can provide numerous benefits to the crop land environments, in addition to fixing nitrogen to the crop in succession. So, our objective was examining the effects of hairy vetch cover crop and N rate to (I) reduce the effect of management zones (MZ) and (II) their N response for grain yield in corn grown in succession. This research was carried out at 2 commercial fields, located in Carazinho - RS, southern Brazil with Typic Hapludox soil type. The management zones were delineated using one yield map from previous year, soil apparent electric conductivity from two depths (0-30 cm and 0-90 cm), terrain elevation and slope. The experimental design was a complete randomized block with three repetitions located within each MZ and the treatments consist of five N rates (0, 60, 120, 180, 240 kg ha^{-1}) with and without hairy vetch (HV) in a tree MZ. The main outcome was that the HV winter cover crop observed was efficient to reduce the productivity gap found among MZ for corn grain yield. Possibly linked to improvements in soil conditions that increased the amount of plant N uptake, especially in the low and medium yield zones where the environment presents less favorable conditions for higher N recovery efficiency top dress applied.

Keywords: Nitrogen Recovery Efficiency. Precision Agriculture. Winter Cover Crop.

INTRODUCTION

Corn (*Zea mays* L.) is one of the main cash crop in Brazil, cultivated in about 16 million hectares (CONAB, 2018) were yields are highly dependent on the level of agricultural technology and the quality of the crop management (RAUN et al., 2011). Corn takes up a significant amount of nitrogen (N) and in soils containing insufficient plant-available N, N addition with fertilizer is needed (TAGARAKIS; KETTERINGS, 2017). Although numerous management factors influence crop response to applied N, identifying the quantity of N required for optimum yield is critical to maximizing net return and crop recovery of applied N (DOBERMANN et al., 2011) and decreases loss of N through leaching and gaseous emissions (THANGARAJAN et al., 2013). Therefore, reaching the synchrony between N supply with plant requirement and low NO_3-N resilience after crop harvest, characterizes one of the main challenges of sustainable agriculture (CAVIGELLI et al., 2013; LAWSON et al., 2012; LAWSON et al., 2015). Accurately estimating the best N recommendations depends on the ability of the recommendation system to accurately estimate field and subfield specific economically optimal nitrogen rates (MORRIS et al., 2018).

In this scenario, in order to accommodate spatially variable landscape conditions with best fertilizer N requirement, the precision agriculture approach involving delineation of spatial variability by creation of management zones (MZ) can be used (FRANZEN et al., 2002; FERGUSON et al., 2003; PERALTA et al., 2015). Precision agriculture is considered the most viable approach in order to reach a sustainable agriculture (KRAVCHENKO; BULLOCK, 2002) and through the use of new and modern sensors accoupled to farm machinery, great amount of georeferenced information can be produced, leading to quantify more accurately the spatial variability of soil and plant variables. Through grouping calculations (FRIDGEN et al., 2004) data are used to delimit continuous zones that show smaller within field variability than between (VELANDIA, 2008) allowing a local specific management (YAO et al., 2014). Therefore, management zones are defined as sub-field of a field that show similar characteristics like soil texture, topography, water and nutrients availability (KITCHEN et al., 2005; BULLOCK et al., 2009; KHOSLA, 2010; MORAL et al., 2010; MORAL et al., 2011) resulting in distinct yield or yield potential factor limitations between them (DOERGE, 1999). Santi et al. (2012), demonstrate that water infiltration is the most pronounced factor explaining within field corn and soybean yield variability in an Oxisol in Brazil. Also, water availability was the main yield limiting factor, even in irrigated areas (MARQUES DA SILVA; SILVA, 2008). Moreover, Doerge (1999) report that the ancillary data permits the MZ delineation, allowing setting up a target N rate for each MZ (ROBERTS et al., 2012).

In order to try to remediate some of the MZ variability limitation for cash crop the use of cover crops species can be useful. Cover crop can lead many important agroecosystems (SNAPP et al., 2005). There are many well-researched benefits to incorporating cover crops into crop rotations, such as their potential to decrease soil erosion, reduce nitrate (NO_3) leaching, increase soil organic matter, reduce pest and weed pressure, and provide additional soil N for cash crops (KASPAR; SINGER, 2011; DORAN; SMITH, 1991). Also, their residue reduces water losses through evaporation and superficial runoff (CLARK et al., 1997; TRUMAN et al., 2003), reduces nutrients leeching (DABNEY et al., 2001) and protect soil against erosive (KASPAR et al., 2001; MARCELO et al., 2012). In another way, their roots contribute to soil aggregation, soil pores and enhanced water availability to plants (VILLAMIL et al., 2006). There are also benefit of weed and pest suppression (TEASDALE, 1993; BURGOS; TALBERT, 1996; HARTWIG; AMMON, 2002; HAYDEN et al., 2012), enhance biological diversity (TILLMAN et al., 2004) and nutrients cycling through residues decomposition (BOER et al., 2007; TORRES et al., 2008; PACHECO et al., 2011).

Hairy vetch (*Vicia villosa* Roth), as a legume crop has a low C:N ratio (mainly 10:1 to 15:1) show quick residue decomposition releasing the N to soil within the first weeks (WAGGER, 1989; RANELLS; WAGGER, 1996; POFFENBARGER et al., 2015). The nutrients from residue decomposition, mainly N, can be used to reduce the N fertilizer requirement in succession crops (CLARK et al., 1997). However, amount of N that remains available generally ranges from 30 to 60% of accumulated N (CLARK et al., 2007; SEO et al., 2006). Another study reports that from the 140 kg ha^{-1} hairy vetch biomass N content, about 26% is recovered by corn cultivated in succession (WHITE et al., 2016).

Because the N content and C:N ratio of cover crop residue can vary widely across different environments and management practices, besides others (CHERR et al., 2006; FINNEY et al., 2016), it is difficult to generalize the N supply potential of cover crop (KETTERINGS et al., 2015).

In this sense, in a precision agriculture scenario the existence of management zones presenting singular soil characteristics, the contribution of legume cover crop may affect the crop yield in succession to response to N fertilization. So, our objective was examining the single and combined effects of hairy vetch cover crop and N rate to (I) reduce the effect of management zones and (II) their nitrogen response for grain yield in corn grown in succession.

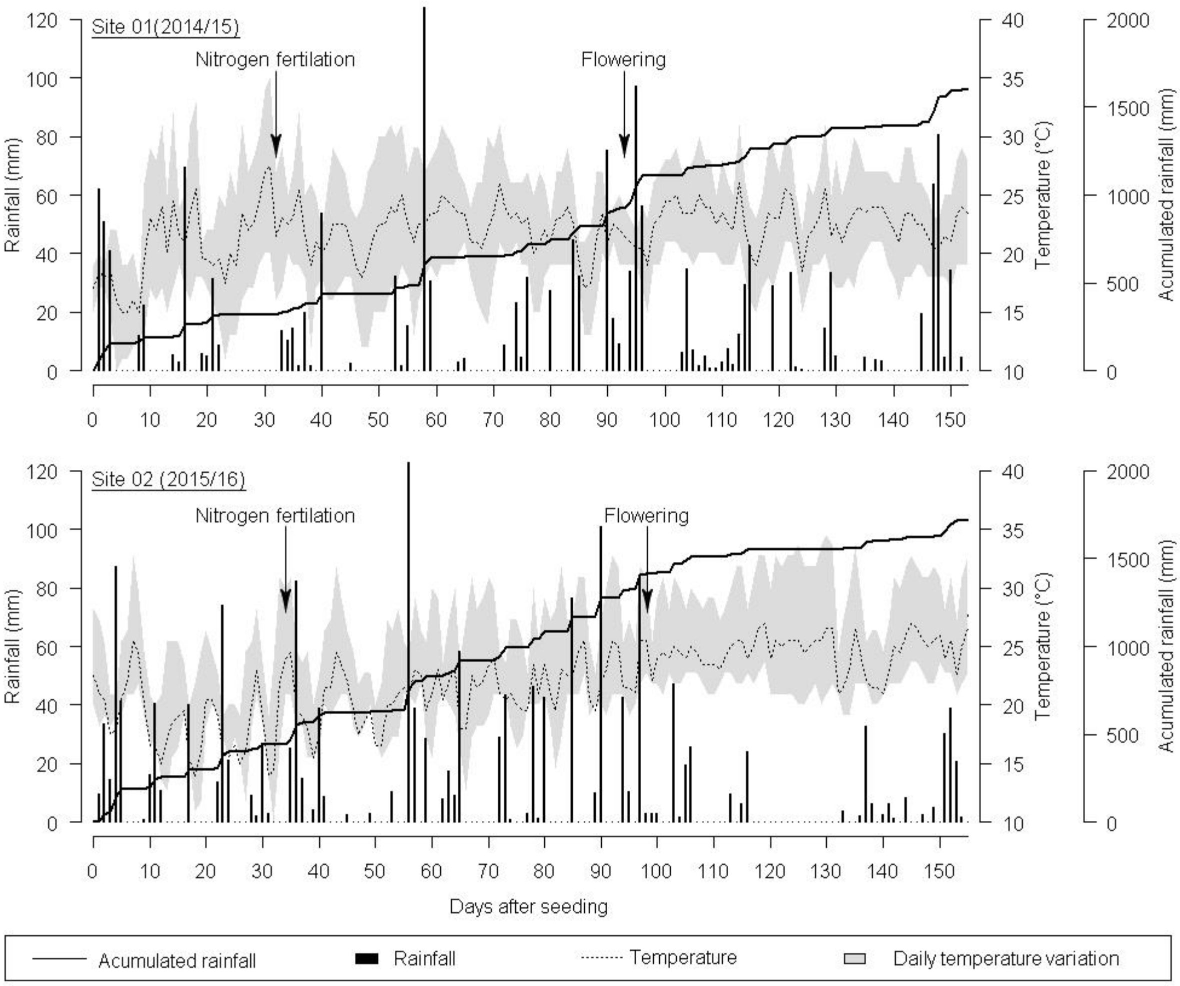
MATERIAL AND METHODS

Description of the experimental fields

This study has been developed near to Carazinho - Rio Grande do Sul, Brazil at two-sites years, the first one (field 1) located in 28.34° S, 52.71° W, carried out during the season 2014/2015 and the second (field 2) located in 28.32° S, 52.73° W, during the 2015/2016 season. The first area was awarded first in the regional stage of the Dupont Colheita Farta contest, with 220 sc ha^{-1} of corn in the 2015/16 season (average in 135 hectare) and the second area was awarded the third prize in the same contest, with 94.47 sc ha^{-1} (weighted average of 60 hectare) of soybeans during the same season. The both award indicates that the producer's management is highly efficient, and theirs fields present high potential to achieve high productivity.

With 610 meters (m) of elevation, the both fields were located closely, and have been managed under long-term no till (more than 10 years) in addition of precision agriculture practices. The landscape is classified as rolling-relief and the dominant soil type is classified as Typic Hapludox according to USDA Soil Taxonomy (2014), deep and well drained. The climate, according to Köppen (1948) classification, is Cfa - humid, the warmest month is January, with an average temperature of 24.6 °C, and the coldest one is June with an average of 12.9 °C. Rainfall is evenly distributed throughout the year ranging from 1500 to 1750 mm. Thus, average daily air temperature and total precipitation data are presented in Figure 1 for all corn growing days.

Figure 1 - Daily and total rainfall, daily temperature and daily temperature variation for both sites, Carazinho - RS, Brazil.



Investigated soil and plant attributes and management zones delineation

The attributes used to delimit the MZ were: soil ECa in two different depths (0-0.30 m and 0-90 m) measured 30 days before the wheat (grass: *Triticum aestivum* L.) seeding, using a Veris® 3100 (Veris Technologies®, Salina – KS, EUA), the sensor was pulled across the field in a series of parallel transects spaced at 15-20 m intervals, appropriate spacing recommend by Farahani and Flynn (2007) to avoid measurement errors and information loss; corn yield data from previous years: 2011/2012 for field 1 and 2012/2013 for field 2 which were filtered using Yield Editor software (SUDDUTH; DRUMMOND, 2007); terrain elevation data obtained from GPS Novatel® with Ominstar HP correction equipped in the combine and slope that was calculated using the terrain elevation data. In addition, Jaynes et al. (2011) and Roberts et al. (2012), report the relevance of topographic components to MZ delineation, once they are related to SOM content, soil physical attributes and mainly with soil water dynamic, influencing processes like water infiltration, runoff and erosion.

All the ancillary data were projected to a metric coordinate system (WGS 1984 UTM Zone 21S) using the rgdal package (BIVAND, 2014) and interpolated in raster maps with a 5 x 5 m grid size using ordinary kriging interpolation based on the gstat package (PEBESMA, 2004), both implemented in R 3.1.3 statistical environment (R CORE TEAM, 2017). In addition, the data from each map were exported in text format using the grid center coordinates, so that the location of the data point for each layer was the same as the layer above and below.

The use of variables with low spatial variability or auto-correlated are not adequate to MZ delimitation. For this purpose, the data was submitted to a principal component analysis (PCA), to transforming interdependent variables in independent ones through a linear transformation comprised the original data set inside a substantially smaller data set of non-correlated variables. So, the new variables from PCA can meet this demand providing new variables called principal components (PC) with uncorrelated data and high degree of data variability explanation (AFIFI; CLARK, 1996). The PCA was performed with R 3.1.3 software using the psych package (REVELLE, 2015).

After, the first two components (PC1 and PC2) with biggest eigenvalues (Supplementary table 1) were extracted to be used in the cluster analysis using the fuzzy c-means algorithm, this technique groups similar individuals into classes, following a dissimilar measure. The cluster analysis was done using the e1071 package (MEYER et al, 2015), with the following settings: Fuzziness exponent = 1.3, maximum number of interactions = 300, convergence criteria = 0.0001, minimal number of zones = 2, maximum number of zones = 6. (ODEH et al., 1992).

For, the best number of MZ was determinate using two indexes, the Normalized Classification Entropy (NCE) that represents the zone homogeneity, and Fuzzy Performance Index (FPI) that represents a measure of the distinction between the groups (ODEH et al., 1992). The optimal number of MZ for a given field is determined when the FPI and NCE each reach a minimum value and were used with success in previous researches (FRAISSE et al., 2001; FRIDGEN; KITCHEN, 2004; ODEH et al., 1992), so we delimited tree and four MZ for field 1 and 2, respectively (Supplementary figure 1).

Finally, the MZ delimitation were submitted to a median filter median filter to replaces the pixel value with the median of the values from the neighborhoods (size mask with 5x5 pixels) of that pixel to promote contiguous zoning and reduce class fragmentation (LARK, 1998; PING; DOBERMANN, 2003; GONZALEZ; WOODS, 2008; CÓRDOBA et al, 2016). So, the result of MZ using the five attributes investigated was classified in low (LYZ), medium (MYZ) and high yield zone (HYZ) and their descriptive analyses was showed in the Supplementary table 2. The MZ thematic maps were generated using Quantum GIS 2.18 software.

Treatments, experimental design and data collection

The experimental design was a complete randomized block with three repetitions located within each MZ, the experimental unit with 24 m² measured 8 m long by 4 m wide. The previous crop in each year was wheat (grass: *Triticum aestivum*, L.) during the winter and soybeans (legume: *Glycine max* L.) during the summer. The hairy vetch (HV) was sown in April (Table 1), approximately 5 months before corn planting and over soybeans dry matter from last season, using a commercial spinner spreader (Model Hercules 5.0, Stara S/A, Não-Me-Toque - RS, Brazil). The dose used to HV seeding was 20 kg ha^{-1} of the Esmeralda varieties in the whole field and after 20 days of emergency the experiment was made by manually scraped with manual brush (Model Brudden K 430 Gasoline 43cc, Brudden Equipments LTDA, Pompeia – SP, Brazil) to create the plots without HV. The HV N apparent uptake and biomass was evaluated through one simple random sample with five sub-samples in a known area (0,25 m^2) around the blocks in September. One day after, whole field were imposed by applying a burn-down herbicide (2 l ha^{-1} a.i. glyphosate) followed by a roll-killed treatment rolling using a manually built roller-crimper to leave HV on the soil surface (Table 1).

Table 1 - Hairy vetch, soil properties and dates of field operations for filed 1 (season 2014/2015) and field 2 (season 2015/2016).

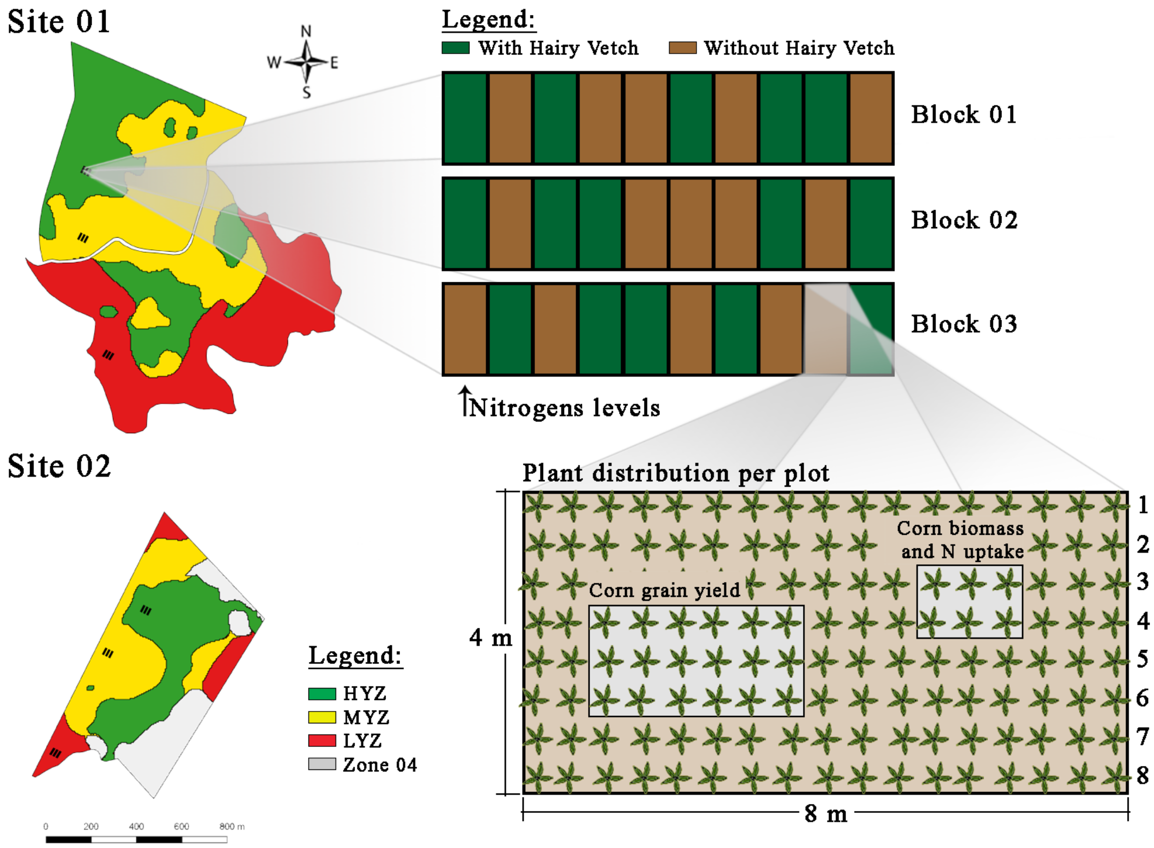
Variables	Field 1 (2014/2015)			Field 2 (2015/2016)		
	LYZ	MYZ	HYZ	LYZ	MYZ	HYZ
Soil properties[1]						
P (mg kg^{-1})	4.2	12.4	13.8	25.2	15.3	14.2
K (mg kg^{-1})	118	156	189	135	134	142
Ca (cmol$_c$ dm^3)	6.3	6.5	6.4	3.5	5.1	6.2
Mg (cmol$_c$ dm^3)	2.9	2.8	2.5	1.2	1.7	2.3
pH	5.4	5.4	5.3	4.6	4.9	5.4
SOM (g kg^{-1})[2]	24	31	32	23	29	32
Clay (g kg^{-1})	500	680	640	420	590	600
Hairy vetch properties						
Dry aboveground biomass (kg ha^{-1})	5332	5589	5834	4234	4563	4724
N content (kg N ha^{-1})	147	159	154	128	142	139
Field operations						
Hairy Vetch planting	15 Abr.			03 Abr.		
Hairy Vetch termination and biomass sampling	15 Sep.			02 Sep.		
Corn planting	28 Sep.			17 Sep.		
N application (V4)[3]	30 Oct.			17 Oct.		
Corn biomass sampling (VT)[4]	21 Dec.			16 Dec.		
Corn manual harvest	29 Feb.			18 Feb.		

[1] Soil samples collected from 0 to 20 cm depth until hairy vetch cover crop planting, [2] Soil organic matter, [3] Fourth leaf, [4] Flowering growth stages

The corn planting (in whole field) was scheduled for 15 days after HV termination, using a commercial planter (Model Princesa Stara S/A, Não-Me-Toque - RS, Brazil) equipped with vSet seed distribution system (Precision Planting, Tremont, IL). The Pioneer hybrid 30F53YH was used and the final plant densities were approximately 64 thousand plants ha^{-1} in both fields. Weeds, diseases and insect pests were controlled adequately during each growing season for whole field.

The treatments consist of five N rates with and without HV in a tree management zones, resulting in 30 plots (Figure 2). The N rates (0, 60, 120, 180, 240 kg ha^{-1} for both fields) were manual top-dress applied in a single application each MZ at V4 (fourth- leaf) corn growth stage (ABENDROTH et al., 2011), using Urea (45 % N) as N mineral fertilizer source. Every experimental unit received 28 kg ha^{-1} of N, 70 kg ha^{-1} of P_2O_5 and 70 kg ha^{-1} of K_2O during the seeding in the both fields.

Figure 2 - Schematic experimental design used in the study.



The N apparent uptake for corn was evaluated trough of one randomized manual sample per plot in a known area (1 m^2) during the flowering growth stages (VT) totalizing 6 plants per plot. The whole aboveground plant was collected (corn and hairy vetch), oven-dried at 75 ºC to constant weight and then weighed and ground for evaluation of N content by the micro-Kjeldhal wet combustion, according to the method described by Tedesco et al. (1995).

To determine the corn grain yield, 18 plants per plot (approximately 3 m^2) were individually harvested and the seed moisture content were determined for each plot and adjusted to 130 g kg^{-1} prior to calculations.

In order to test the significance of the treatments and their interactions compare treatments within each MZ, including the N rate x MZ interaction and presence of HV, one mixed linear model (MLM) of ANOVA was adjust (Eq. 1) for corn grain yield, N apparent uptake and N apparent recovery efficiency (NRE) (kg increase in plant N uptake per kg N applied).

$$Y_{ijkl} = \mu + E_i + N_j + B_k + Z_l + EN_{ij} + EZ_{il} + NZ_{jl} + ENZ_{ijl} + B(Z)_{k(l)} + \varepsilon_{ijkl}$$

(Eq. 1)

Where μ is the overall experimental average; E is the fixed effect of Hairy Vetch as cover crop (i = 1,2); N is the fixed effect of N fertilizer rate (j = 1,2,3,4,5); B is de random effect of block (k = 1,2,3); Z is the fixed effect of the MZ (l = 1,2,3); $B(Z)$ is the random effect of block within the management zone (k = 1,2,3) and ε_{ijkl} is the random error which is potentially correlated under two covariance models: a random block (RB) model, and the random model plus spatial correlation of plot errors (RB + SP). For the RB + SP models, exponential, gaussian and spherical correlation functions without nugget effect were evaluated using the nlme package (PINHEIRO et al. 2015) of the R statistical software. These models (RB, RB + SP(Exp), RB + SP(Gau), RB + SP(Sph)) were adjusted with homogenous and heterogeneous variances for the different MZ. When compare homoscedastic and heteroscedastic models the Likelihood Ratio Test (LRT) was used (WEST et al., 2007) and selected was done following the Akaike information criteria (AIC).

All other data were analyzed without transformation, and the differences between means were compared by the Least Significant Differences (LSD) test with Tukey-Kramer adjustment at the P= 0.05 significance level. When there was interaction among MZ, Vetch as cover crop and N rates a linear regression analysis was done independently for each MZ. The criteria to choose the model more suitable were the significance by the F test, the highest determination coefficient (R^2) and the smaller residual sum square.

Finally, the NRE was calculated using the equation suggested by Dobermann (2005) (Eq. 2).

$$NRE = (NU_N - NU_C)/X_N$$

(Eq. 2)

Where NRE is the N apparent recovery efficiency (kg kg^{-1}); NU_N is the N uptake in the treatment with N fertilization (kg ha^{-1}); NU_C is the N uptake in the control treatment (without N fertilization) (kg ha^{-1}) and X_N is the N fertilization (kg ha^{-1}).

RESULTS AND DISCUSSION

Effects of treatments and their interactions

In all variables from both fields, the randomized blocks were sufficient to account for spatial correlation, indicating that the blocks were relatively homogenous. Moreover, it was necessary to differentiate residual variances within each MZ because the heterogeneous residual variance was considered more accurate in each level of MZ factor (Table 2).

All the effects of N rate, MZ, HV and their interactions were assessed through the selected models. A significant ($P<0.05$) tree-way ANOVA interaction was not observed for any variable, however, all the two-way ANOVA interactions was found for corn grain yield and apparent total nitrogen uptake (ATNU) (Table 3), moreover the MZ x N rate interaction for NRE was not observed. Thus, indicating that the response to fertilization differs for the MZ or in presence of HV and the result was evaluated individually.

Table 2 - Akaike Information Criteria (AIC) for model selection.

Variables	Models							
	RB	RB_H	RB + SP(Exp)	RB + SP(Exp)_H	RB + SP(Gau)	RB + SP(Gau)_H	RB + SP(Esf)	RB + SP(Esf)_H
Field 1								
Grain yield	1010.394	1007.218[1] (0.6622)[2]	1012.394	1009.218	1012.394	1009.218	1012.394	1009.218
ATNU[3]	544.9336	544.0728 (0.2081)	546.9211	546.0728	546.8744	546.0728	546.8715	546.0728
NRE[4]	-30.3936	-30.60965 (0.1508)	-28.39675	-28.61857	-28.43656	-28.66107	-28.51663	-28.70898
Field 2								
Grain yield	943.607	943.1077 (0.1737)	945.607	945.1077	945.607	945.1077	945.607	945.1077
ATNU	514.6979	512.5456 (0.397)	516.3958	514.3174	516.3883	514.3357	516.3877	514.336
NRE	-60.21932	-62.98431 (0.0243)	-58.42212	-60.55547	-58.4228	-60.54141	-58.4228	-60.54063

RB = Random block model; RB+ SP = Random block model plus spatial correlation of plot errors (Exp for Exponential, Gau for Gaussian and Sph for Spherical correlation functions), [1] The lower AIC value indicates a better model accuracy, [2] In parenthesis, p-value for Likelihood Ratio Test comparing the heteroscedastic model against the same correlation model with homogeneous variance between management zones, [3] Apparent total nitrogen uptakes, [4] Nitrogen apparent recovery efficiency.

Table 3 - Analysis of variance for corn grain yield and total N uptake, resulting from 5 N rate applied to corn that receive or not hairy vetch as winter culture in three different management zones in field 1 and 2.

		Field 1			Field 2		
Effect	DF[1]	Grain yield	ATNU[2]	NRE[3]	Grain yield	ATNU	NRE
MZ[4]	2	<.0001	<.0001	0.0013	<.0001	<.0001	0.0073
Hairy vetch	1	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
N rate	4	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
MZ × Hairy vetch	2	0.0252	0.0195	0.0259	0.0011	0.0200	0.0011
MZ × N rate	8	0.0282	0.0014	0.9285	0.0001	0.0011	0.5111
Hairy vetch × N rate	4	0.0424	<0.0001	0.0157	0.0007	<.0001	0.0366
MZ × Hairy vetch × N rate	8	0.5898	0.1108	0.2342	0.7836	0.2137	0.5697

[1] Degrees of freedom, [2] Apparent total nitrogen uptakes, [3] Total apparent nitrogen uptakes, [4] Management zones.

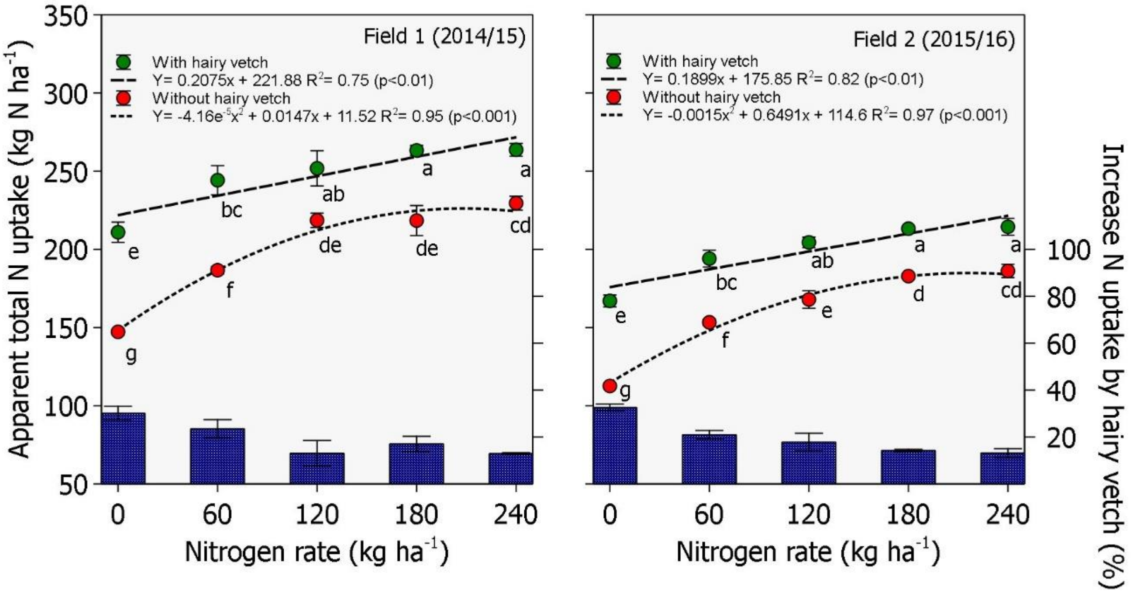
Apparent total nitrogen uptake

In the field 1, the corn ATNU without HV in the winter season ranged from 135 to 263 kg ha^{-1} and with HV the range was from 185 to 291 kg ha^{-1}, whereas, in the field 2 the ATNU ranged from 94 to 223 kg ha^{-1} for treatments that do not receive cover crop, and 140 to 237 kg ha^{-1} for treatments with HV. The two experiments receive the same N rates ranging from 0 to 240 kg ha^{-1}, however the large of ATNU in the field 1 in relation to field 2 was due to the better weather conditions during the corn growing season (2014/15), mainly related to lower daily average temperatures with hot days and colder nights if compared to the field 2. Moreover, higher amount of precipitation after the N application in the second field (season 2015/2016) probably contributed to N losses by leaching when compared to the field 1, which received better distributed rainfall (Fig. 1).

Without MZ effect, the ATNU present the higher values for treatments with HV and increased linearly or according to second-order polynomial equations, across the entire range of N application rates (Fig. 3). After 120 kg N ha^{-1} rate, no significant increases ATNU were observed for treatments with and without HV in field 1. Moreover, this was the rate from non-HV treatment that presented equivalence with the treatment that received HV in the winter, but without N manual top-dress applied.

Contributions from annual legume green manure crops can range from 0 to 159 kg N ha^{-1} (OYER; TOUCHTON, 1990; REINBOTT et al., 2004; CLARK et al., 2007). For this study, HV provide a good part of the N absorbed by the plant with and without N fertilization. When subtracting the ATNU between treatments with and without HV, we suppose that in general (for all MZ) the ATNU was similar and reached 63 and 55 kg of N ha^{-1}, for the first and second field, respectively (Fig. 3).

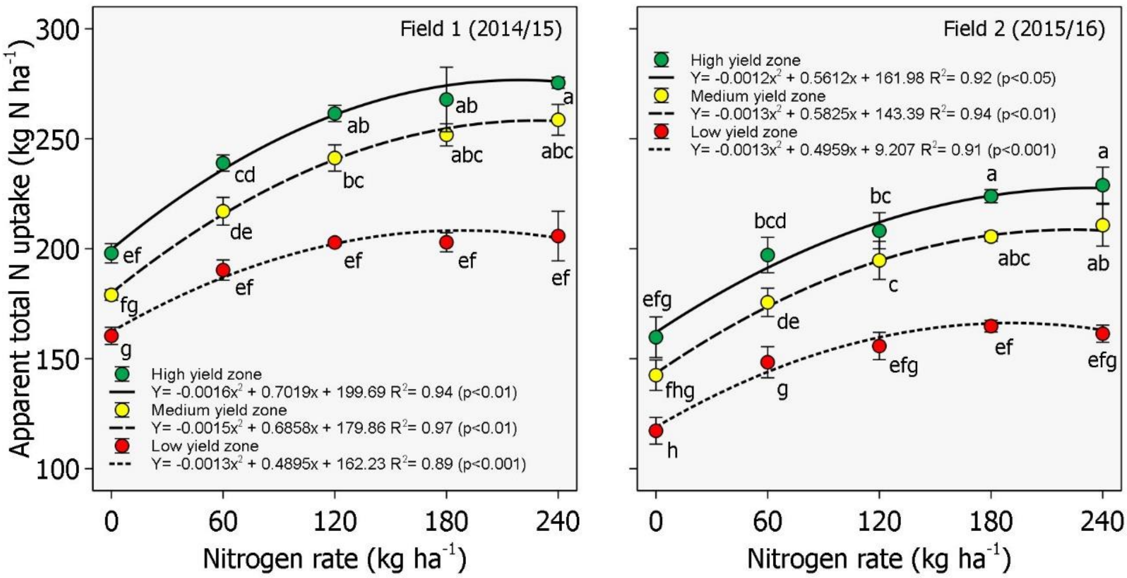
Figure 3 - Apparent total nitrogen uptake influenced by N fertilizer rate (from 0 to 240 kg ha^{-1}) with and without hairy vetch as winter cover crop for field 1 and field 2. Data followed by the same letter within seasons are not significantly different. Values followed by the same letter within fields are not significantly different (*P*<0.05). Vertical bars indicate standard error of mean for each value.



The first objective of N fertilization is to increase the plant ATNU, improving the plant nutritional status. The interaction between N rate and MZ responded positive and gradually lower by quadratic polynomial mathematical adjustment. The low yield zone (LYZ) present limited absorption of N, especially in the field 2 where the weather conditions were somewhat less favorable (Fig. 4). In this way, the use of high N fertilizer rates in the LYZ can increase the environmental risk, because of low N fertilizer recovery by plants. This residual N would be subject to losses by volatilization, leaching and denitrification depending on prevailing weather conditions and soil characteristics (NIELSEN, 2006). Furthermore, Inman et al. (2005) and Khosla et al. (2008) reported that at the LYZ the corn plants, independent of the N rate investigated, always showed the lowest apparent N uptake between the evaluated zones.

The amount of ATNU without HV in fields 1 and 2, was 31 and 43 % greater in the high yield zone (HYZ) than tin the LYZ, respectively (Fig. 5). This higher ATNU documented in the HYZ, regardless the field, is probably due to SOM content and the topographic attributes (SOON; MALHI, 2005). Jaynes et al. (2011) and Roberts et al. (2012) reported the relevance of topographic attributes to MZ delineation was related to SOM content, soil physic attributes and mainly with soil water dynamics, influencing processes like water infiltration, runoff and erosion. Moreover, Kravchenko and Bullock (2000) and Jiang and Thelen (2004) also found correlations between topographic attributes and corn yield were field-specific.

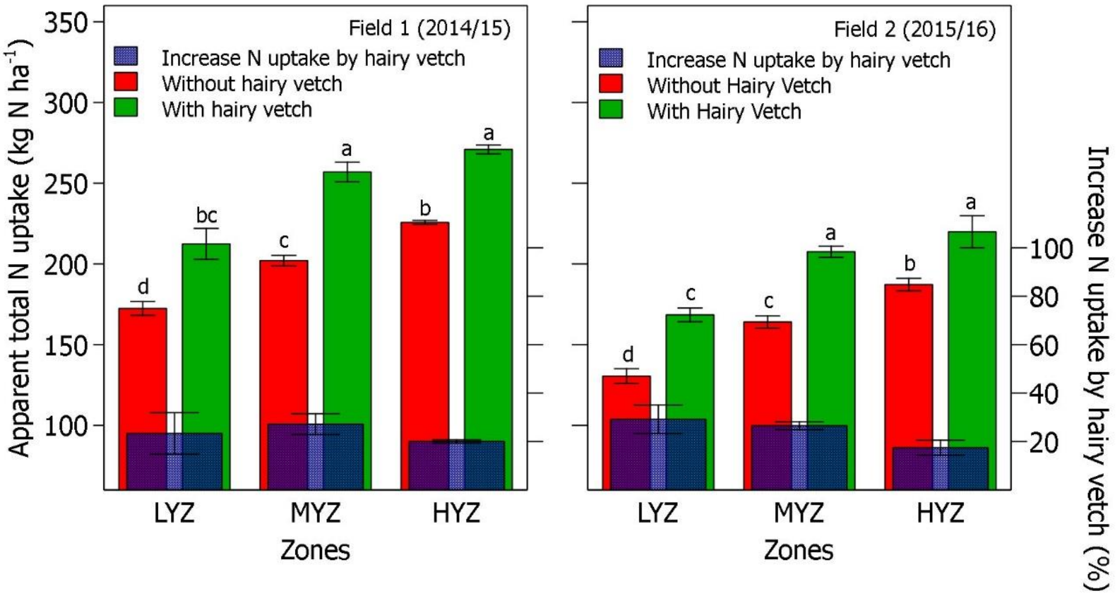
Figure 4 - Apparent total nitrogen uptake influenced by N fertilizer rates (from 0 to 240 kg N ha^{-1}) in the management zones, for field 1 and field 2. Values followed by the same letter within fields are not significantly different ($P<0.05$). Vertical bars indicate standard error of mean for each value.



Peralta et al. (2015) previously reported that the soil water availability was the preponderant factor to justify greater plant N uptake in the HYZ. In this same way, Khosla et al. 2008 and Marques da Silva and Silva 2008 reported the strong relationship with soil water dynamics, plant nutrient uptake and crop yield potential influenced by the topographic factors. In this study, the LYZ had the highest slope, averaging 12 and 7% for fields 1 and 2 respectively (Supplementary table 2), and the lowest SOM (Table 1). Thus, the results of the analysis suggest that areas with the highest slope, as observed in the LYZ (Supplementary table 2), will likely present less plant ATNU and N fertilization response as compared to other MZ.

In presence of HV cover crop, the corn plants were able to absorb more N in all the MZ studied, expressing greater gains in all MZ, mainly in the LYZ and medium yield zone (MYZ), where the slope is higher The Fig. 5 shows the effect of HV cover crop on corn ATNU at stage VT for different MZ, that showed different results each MZ, increasing 23, 27 and 20% for the low, medium and high yield zones in the first field and 29, 26 and 17% for the low, medium and high yield zones in the second field. This positive effect made by the HV cover crop could be attributed to the improvement of soil conditions that promotes water and nutrient storage, through its biomass and root system.

Figure 5 - Apparent total nitrogen uptake influenced by hairy vetch in tree management zones for field 1 and field 2. Values followed by the same letter within fields are not significantly different ($P<0.05$). Vertical bars indicate standard error of mean for each management zone.

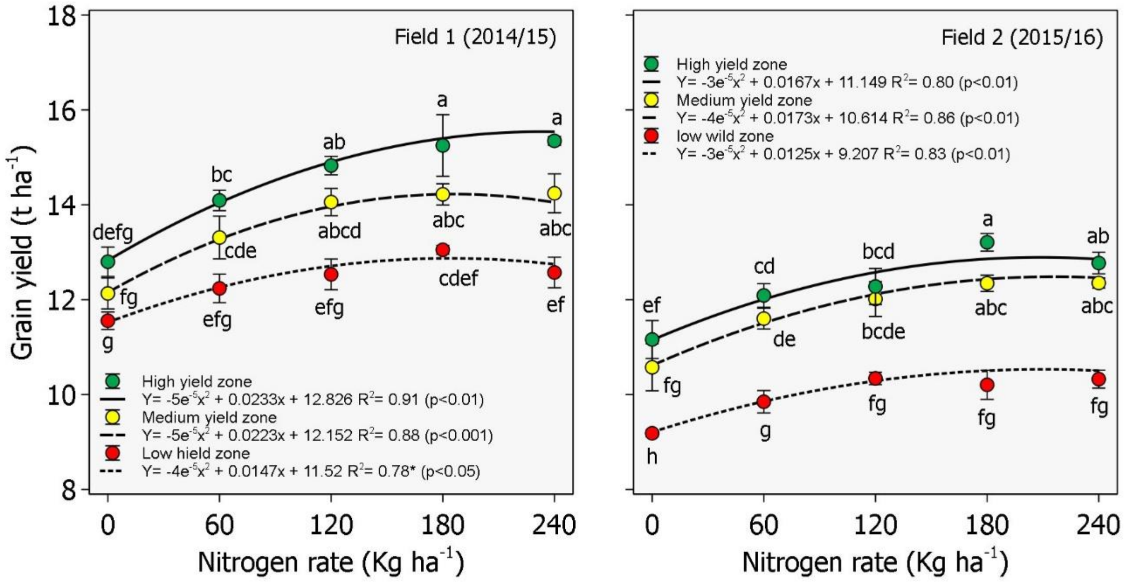


Corn grain yield affect by MZ, hairy vetch, N rate and their interactions

Similar to the plant ATNU the corn grain yield response to N fertilizer rates followed a quadratic polynomial adjustment regardless of MZ (Fig. 6) and presence of HV cover crop (Fig. 7) investigated. In the first field, only with the base fertilization (28 kg ha^{-1}) the treatments showed a grain yield 5.5% and 10.8% higher than the medium and low yield zone, respectively. The Agronomic Optimum Nitrogen Rate (AONR) calculated was 177, 194 and 217 kg N ha^{-1} producing 12826, 14322 and 15354 kg ha^{-1} of grain yield LYZ, MYZ and HYZ, respectively. In the same line, the site 02 only with the base fertilization showed a grain yield 5.5% and 21.5% higher than the medium and low yield zone, respectively. The AONR calculated was 184, 205 and 212 kg N ha^{-1} producing 10365, 12384 and 12919 kg ha^{-1} of grain yield to low, medium and high yield zones, respectively (Fig. 6).

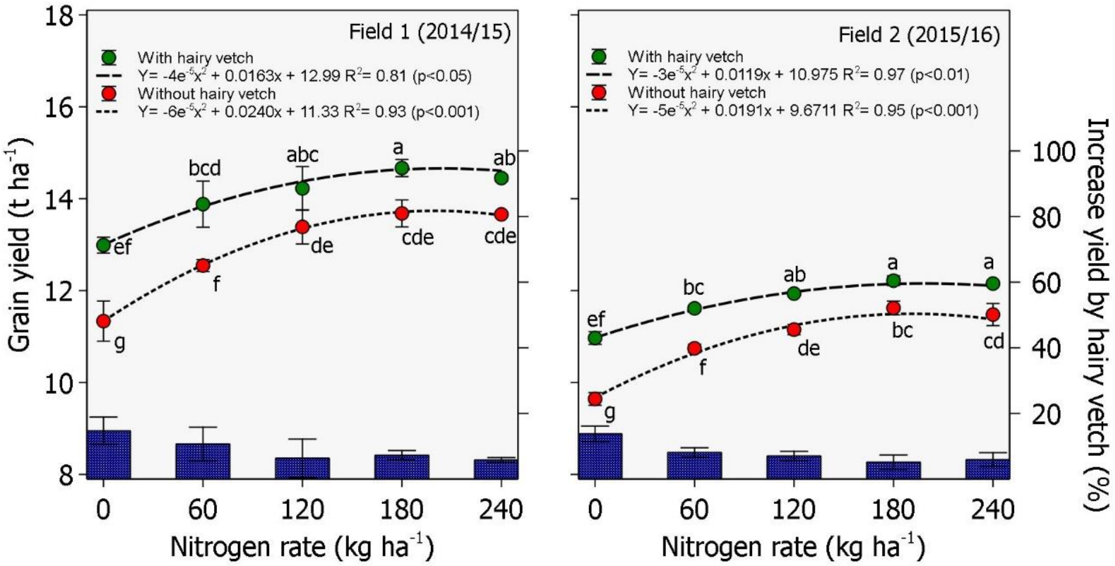
The occurrence of a plateau for N rates in each MZ was observed first to LYH, followed by MYZ and HYZ (Fig. 6), with different corn grain yield responses to N fertilizer rate among the MZ. Similar results were previously reported for Khosla et al. (2008), Janeys et al. (2011) and Roberts et al. (2012). However, some authors (SHANAHAN et al., 2008; RAUN et al., 2011) also reported MZ concept alone it is not adequate for improving variable N application of corn grain yield.

Figure 6 - Corn grain yield influenced by N fertilizer rates (from 0 to 240 kg N ha^{-1}) in the management zones, for field 1 and field 2. Values followed by the same letter within fields are not significantly different ($P<0.05$). Vertical bars indicate standard error of mean for each value.



Previous research show that HV winter cover crop can supply all or part of nitrogen necessary to reach high corn grain yield, (RANELLS; WAGGER, 1996; TONITTO et al., 2006; CLARK et al., 2007; TEASDALE et al., 2012). Thus, the performance of N fertilizer rates, differed significantly with and without HV cover crop, and only with the basic fertilization (28 kg of N ha^{-1}) for treatments that received HV winter cover crop were enough to reach statistically similar grain yield to treatments that received 180 kg of N ha^{-1} for field 1 and 120 kg of N ha^{-1} for field 2 (Fig. 7). Which agrees with the greater climatic conditions (Fig. 1) and plant ATNU in field 1 (Fig. 3).

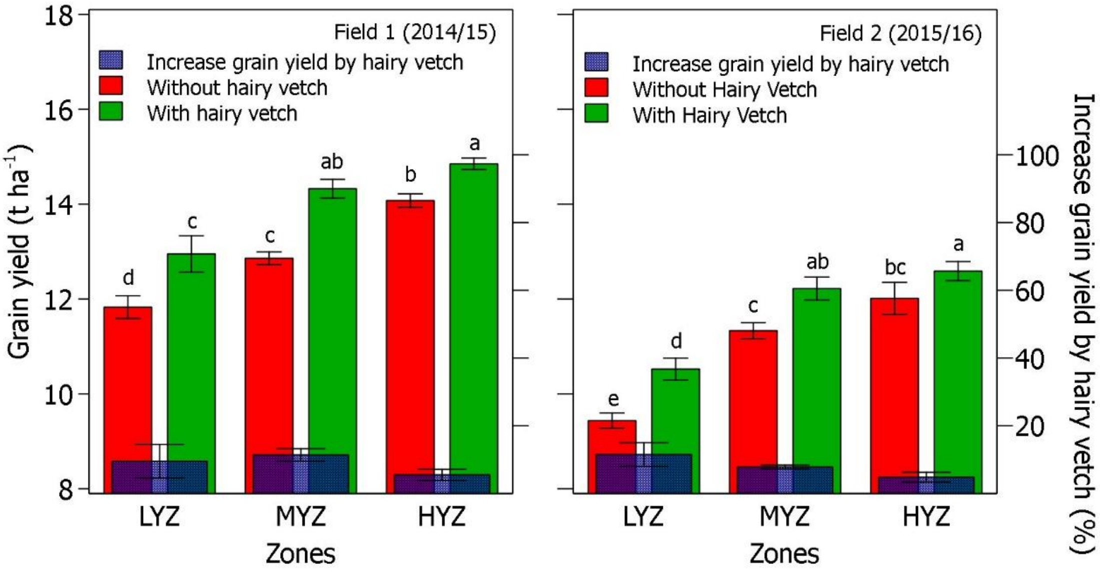
Figure 7 - Corn grain yield influenced by N fertilizer rate (from 0 to 240 kg ha^{-1}) with and without hairy vetch as winter cover crop for field 1 and field 2. Data followed by the same letter within seasons are not significantly different. Values followed by the same letter within fields are not significantly different ($P<0.05$). Vertical bars indicate standard error of mean for value.



Independent of N rate, the corn grain yield shown high in presence of HV cover crop in all MZ (Fig. 8). The field 1 showed weather conditions more favorable to express the productivity difference between the presence and absence of the coverage plant in the same MZ. For field 1 the corn grain yield in absence of hairy vetch cover crop was 11829, 12858 and 14074 kg ha^{-1} for low, medium and high yield zones, respectively and showed statistical deference among the tree yield zones. But, in the presence of HV winter cover crop, the corn grain yield produces 12590, 14325 and 14850 kg ha^{-1} for low, medium and high yield zone, respectively without statistical diference between medium and high yield zone. Furthermore, the field 2 don't present statistical difference for grain yield, between medium and high yield management zones without HV cover crop, probably because the field 2 has more similar zones, since one of its zones has not been studied.

In the field 1 the corn grain yield range for LYZ without hairy vetch was 1739 kg ha^{-1}, 39.0% higher than hairy vetch cover crop (1252 kg ha^{-1}), in the same way, difference of 48.0% (2638 to 1784 kg ha^{-1}) for MYZ and 44.0% (3006 to 2088 kg ha^{-1}) for HYZ was found when the cover crop was removed from the system (Fig. 8). In the field 2, the relative difference between treatments means remained similar those of the first year, where MYZ decreased its yield gap by 54.0% (2090 to 1353 kg ha^{-1}) followed by HYZ with 51.0% (2464 to 1632 kg ha^{-1}) and LYZ with 47.0% (1473 to 999 kg ha^{-1}) (Fig. 8).

Figure 8 - Corn grain yield influenced by hairy vetch in tree management zones for field 1 and field 2. Values followed by the same letter within fields are not significantly different (*P*<0.05). Vertical bars indicate standard error of mean for each management zone.



Corn grain yield in management zones affect by nitrogen recovery

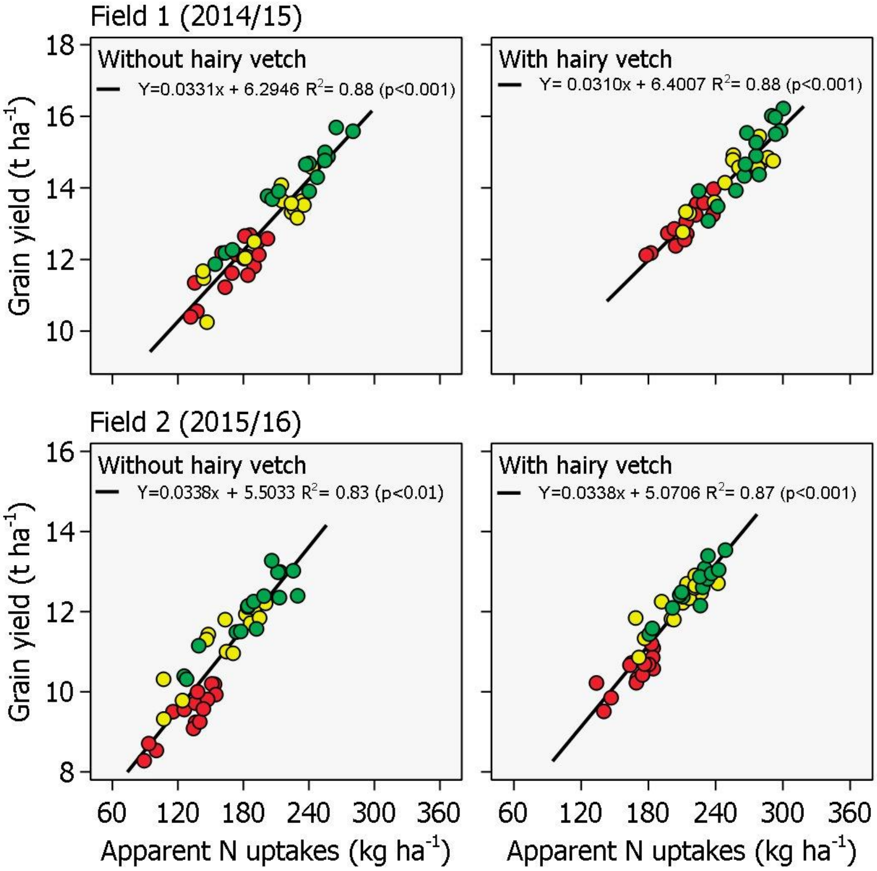
Numerous properties influence the suitability of soil as a medium for crop growth and yield. Previous research has shown that slope is correlated with yield and nutrient availability, because the plant roots absorb nutrients better at low slope; high water-holding capacity in these areas results in higher-yielding areas. The same was observed, for both sites, a higher frequency of areas with high slope, mainly LYZ (Supplementary table 2). Thus, Kaspar et al. (2003) and Kravchenko et al. (2005) repost that this normally tends to diminish the infiltration rate and the soil water-holding capacity.

In addition, Clark et al. (1997), Dabney et al. (2001) and Truman et al. (2003) and report that the HV reduces the water losses through evaporation, superficial runoff and nutrients leeching. Moreover, Santi et al. (2012) reported that water infiltration was the main factor, which explains corn and soybean grain yield variability in an Oxisoil in southern Brazil.

The use of cover crops in row crop systems has been reported to improve ecosystem services provided by the row crop systems including influence soil physical conditions and water retention (DRURY et al., 2003; PAPADOPOULOS et al., 2006). This increase is probably attributed to the ability of HV winter cover crop to provide N to the maize crop, through the partial or total reduction of the effects that minimize the efficiency of the use of nitrogen obtained in higher productivity environments. Thus, increments in the order of 10.5 and 9.6% were found for the low and medium productivity zones, respectively, which represents the double found in the zone of high productivity (5.1%) (Fig. 8).

In this way, the 95% confidence intervals of the coefficients for the regression involving N uptake and corn grain yield, thus a linear adjustment was sufficient to describe the relationship between these variables. Showing strong relation between the N uptake by the plant and the corn grain yield (Fig. 9).

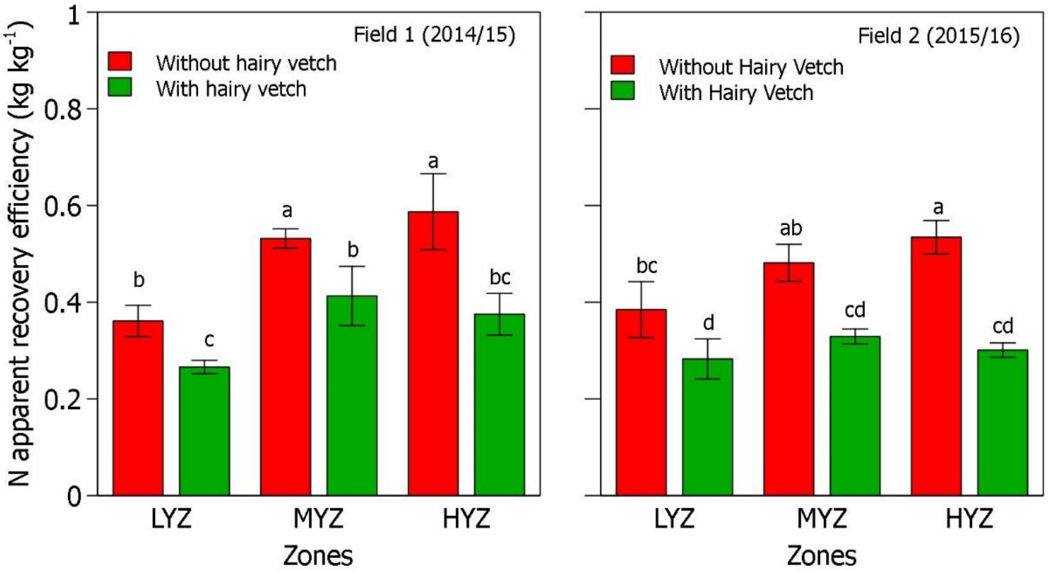
Figure 9 - Regression analysis between corn N uptake and grain yield in affect by hairy vetch as or not cover crop in tree management zones (High yield zones = green points, medium yield zones = yellow points and low yield zones = red points).



Moreover, the productivity difference found between the high and low zone was 2.2 and 1.9 Mg ha^{-1} in the presence or absence of HV for the field 1 and 2.6 and 2.1 Mg ha^{-1} for the field 2. Thus, the higher productivity increase observed in the medium and low areas contributed to the achievement of less distinct productivity among the MZ for grain yield in corn grown in succession.

Finally, as expected, the N recovery efficiency under the presence of HV was lower than absented of HV, because it contributes to the fixation of N to the environment even in the treatments that did not receive N in coverage and showing higher yields in the reference treatment (0 kg N ha-1). Thus, in the presence of HV, the N apparent recovery efficiency applied was more homogeneous among all the zones, which characterizes a buffering effect that result in the reduction of the differences for corn grain yield among the MZ. (Fig. 10).

Figure 10 - Nitrogen apparent recovery efficiency influenced by hairy vetch in tree management zones for field 1 and field 2. Values followed by the same letter within fields are not significantly different (*P*<0.05). Vertical bars indicate standard error of mean for each management zone.



CONCLUSIONS

The effects of HV winter cover crop observed was efficient to reduce the productivity gap found among MZ for corn grain yield. Possibly linked to improvements in soil conditions that increased the amount of plant N uptake, especially in the low and medium yield zones where the environment presents less favorable conditions for higher N recovery efficiency top dress applied.

For this experiment, N rates of 120 and 180 kg N ha^{-1} top dress applied for field 1 and field 2, respectively, associated with HV winter cover crop presented the best productivity responses for corn grain yield.

Thus, increasing in order of 23, 27 and 20% for the low, medium and high yield zones in the first field and 29, 26 and 17% for the low, medium and high yield zones in the second field in the presence os HV cover crop.

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APPENDICES

Table 4 - Principal component analysis for the first and second fields.

	Field 1		Field 2	
Variance components	Principal components			
	1	2	1	2
Eigenvalue	2.9428	0.8673	2.1694	1.5623
Proportion (%)	59.15	17.43	43.7	31.47
Accumulated proportion (%)	59.15	76.58	43.7	75.17
Attributes	Factor loadings			
Corn grain yield	-0.4159	0.5588	-0.6369	-0.0564
Elevation	-0.5229	0.3010	-0.6454	0.0224
ECa[1] 0-30cm	-0.3885	0.2103	-0.3900	-0.1029
ECa 0-90cm	-0.4458	-0.5019	0.1400	-0.6985
Slope	0.4515	0.5487	0.0788	0.7040

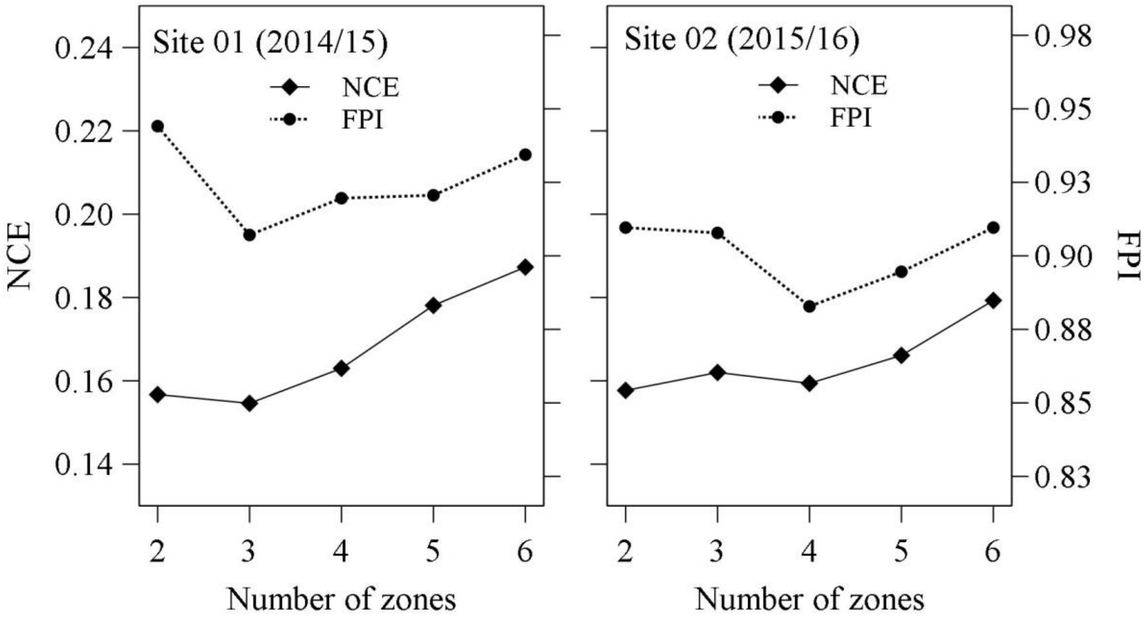
[1] Soil apparent electric conductivity.

Table 5 - Descriptive analysis of soil and plant attributes within the management zones for field 1 and field 2.

Field 1					
Attribute	MZ	Average	CV (%)	Min	Max
ECa[1] 0-30cm (mS m^{-1})	HYZ	8.49 a	8.35	6.57	10.40
	MYZ	7.45 b	8.64	5.88	9.22
	LYZ	6.49 c	20.04	3.53	9.44
ECa 0-90cm (mS m^{-1})	HYZ	108.24 a	10.58	79.33	136.75
	MYZ	94.68 b	9.82	68.47	115.47
	LYZ	74.17 c	14.99	47.83	103.49
Elevation (m)	HYZ	533.34 b	1.04	516.03	546.63
	MYZ	541.66 a	0.98	524.49	548.29
	LYZ	517.59 c	1.67	497.48	539.77
Slope (%)	HYZ	6.53 b	34.89	0.53	17.24
	MYZ	4.04 c	49.27	0.02	12.56
	LYZ	12.21 a	29.98	0.81	24.46
Corn grain yield (kg ha^{-1})	HYZ	8461.8 a	19.01	3101.4	11277.6
	MYZ	7270.2 b	20.31	3158.4	10781.4
	LYZ	5760.6 c	24.63	2832.6	10947.6
Field 2					
Attribute	MZ	Average	CV (%)	Min	Max
ECa 0-30cm (mS m^{-1})	HYZ	8.08 a	6.06	6.57	9.27
	MYZ	6.40 b	9.77	4.67	7.97
	LYZ	5.04 c	12.90	3.90	9.03
ECa 0-90cm (mS m^{-1})	HYZ	90.53 a	5.85	73.26	101.33
	MYZ	71.64 b	9.36	56.21	91.11
	LYZ	59.58 c	12.09	46.53	97.13
Elevation (m)	HYZ	563.15 c	0.65	552.68	571.09
	MYZ	569.58 a	0.43	558.13	573.95
	LYZ	564.04 b	0.52	553.98	572.62
Slope (%)	HYZ	5.10 b	32.31	0.08	9.25
	MYZ	3.66 c	44.36	0.15	16.57
	LYZ	7.01 a	51.74	0.01	16.77
Corn grain yield (kg ha^{-1})	HYZ	11507.4 a	7.28	7956.3	13378.2
	MYZ	11258.4 b	8.55	8107.8	13561.8
	LYZ	8572.2 c	5.55	7757.4	10701.0

[1] Soil apparent electric conductivity. Same letters are not significantly different (Tukey with significance level of 5 %).

Figure 11 - Normalized Classification Entropy (NCE) and Fuzzy Performance Index (FPI) for experimental fields 1 and 2.



5 CONCLUSÃO

Através dos resultados encontrados perante os dois experimentos não foram observadas intereções triplas entre os fatores avaliados, porém todas as intererações duplas se mostraram significativas.

A quantidade de nitrogênio aparente deixada pela cultura da ervilhaca peluda foi de 64 kg N ha^{-1} para o primeiro experimento e 54 kg N ha^{-1} para o segundo experimento. Sendo que diferenças de produtividade não foram encontradas após a utilização de 120 kg N ha^{-1} para o primeiro experimento e 180 kg N ha^{-1} para o segundo experimento.

A presença da ervilhaca peluda como cultura de cobertura contribuiu de maneira diferente para cada zona de manejo, apresentando incrementos na ordem de 23, 27 e 20% para as zonas de baixa, média e alta produtividade, resepectivamente para o primeiro experimento e 29, 26 and 17% para as zonas de baixa, média e alta produtividade no segundo experimento.

Para o presente experimento a ervilhaca peluda foi eficiente em aumentar a homogeneidade da produtividade de milho como cultura sucessora entre as zonas de manejo. Fato possivelmente atrelado as melhorias nas condições e qualidades do solo que elevaram a recuperação aparente de nitrogênio pela planta, principalmente nas zonas de baixa e média produtividade, na qual o ambiente apresentava condições menos favoráveis para altas eficiências na recuperação do N aplicado em cobertura.

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