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Sistemas integrados de produção agropecuária: o papel da pastagem na solução do dilema produção *versus* conservação

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“A resposta certa, não importa nada: o
essencial é que as perguntas estejam certas.”

Mário Quintana

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SISTEMAS INTEGRADOS DE PRODUÇÃO AGROPECUÁRIA: O PAPEL DA PASTAGEM NA SOLUÇÃO DO DILEMA PRODUÇÃO *VERSUS* CONSERVAÇÃO [1]

Autora: Taise Robinson Kunrath
Orientador: Paulo César de Faccio Carvalho
Co-orientador: Gilles Lemaire

Resumo – Além dos fins produtivos, as pastagens desempenham importante papel na preservação ambiental e na dinâmica da atmosfera e hidrosfera. Esta tese apresenta dois trabalhos, que demonstram as duas faces da pastagem nos sistemas produtivos. O primeiro trabalho, se refere a produção aliada à conservação e teve por objetivos (i) verificar se existe padrão no comportamento das variáveis de produção animal de pastos manejados em diferentes alturas e (ii) identificar metas de manejo que aliem produção e conservação. Este trabalho foi desenvolvido em um sistema integrado de produção agropecuária (SIPA) de longo prazo (2001-2011), localizado na região sul do Brasil. Os tratamentos consistiram de quatro alturas de manejo do pasto: 10, 20, 30 e 40 cm, delineados em blocos ao acaso, com três repetições. Foram utilizados novilhos com idade inicial média de 12 meses, sob pastoreio contínuo com taxa de lotação variável. As variáveis de produção animal e de pasto estudadas mostraram-se afetadas pelos anos experimentais. No entanto, existe padrão nas relações entre produção animal e de pasto ao longo dos 10 anos de experimento. A altura de manejo do pasto de 30 cm permite o acúmulo de resíduo sobre o solo, que beneficia o SIPA, e que proporciona ganho animal satisfatório e estável ao longo dos anos. O segundo trabalho, de cunho conservacionista, objetivou avaliar (i) o efeito de diferentes períodos de duração da pastagem em sistemas de rotação de cultura na drenagem e lixiviação de nitrogênio; (ii) o impacto do nível de intensificação, mais precisamente do uso da adubação nitrogenada durante a fase de pastagens; e (iii) analisar se ocorre um pico de lixiviação após a saída da pastagem e retorno das culturas de grãos, como conseqüência de uma maior mineralização N. Foi realizado na Região centro-oeste da França, com uma base de dados de 9 anos, comparando sistemas de rotação de cultura de milho, trigo e cevada com diferentes períodos de participação de pastagem mista de *Festuca arundinacea, Lolium perenne* e *Dactylis glomerata* (0, 3, 6 e 20 anos). Concluiu-se que a introdução de pastagem na rotação de culturas reduz a concentração de nitrato na água drenada. Quanto maior o tempo de participação da pastagem, maior é a redução na concentração de nitrato e, consequentemente, menor a lixiviação de nitrogênio, independentemente da adubação nitrogenada durante a fase pastagem.

Palavras-chave – Drenagem; Lixiviação; Nitrato; Pastejo; Produção animal.

[1] Tese de doutorado em Zootecnia – Plantas Forrageiras, Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil. 130p. Agosto, 2014.

INTEGRATED CROP-LIVESTOCK SYSTEMS: THE ROLE OF GRASSLAND IN SOLVING THE DILEMMA PRODUCTION VERSUS CONSERVATION[1]

Author: Taise Robinson Kunrath
Advisor: Paulo César de Faccio Carvalho
Co-advisor: Gilles Lemaire

Abstract – Further to productive targets, grasslands present an important role in environmental preservation and the atmospheric and hydrospheric dynamics. This thesis presents both issues, demonstrating the two roles of pastures in productive systems. The first work, refers to production with to conservation, and the objective was (i) verifying the pattern in animal and pasture production under different swards heights and (ii) identifying management targets that combine production and conservation. This work was carried out in a long term integrated crop-livestock system (ICLS) (2001-2011) in Southern Brazil. Treatments consisted of four swards heights: 10, 20, 30 and 40 cm, in a randomized block design with three replicates. Steers 12 months old were used, under continuous grazing with variable stocking rates. Animal and sward production were affected by the years effect, however, there are pattern on animal-sward relationship throughout ten years of experiment. 30 cm sward height allows soil residue accumulation that enables satisfactory livestock weight gain along the years on ICLS. The second work, which had more conservation nature, had the objectives: (i) the quantification of the grassland effect on drainage water quality at the level of a whole crop rotation according to the duration of the "grassland" phase and then on the relative importance of grassland area vs arable cropping area in the land use system; (ii) the impact of the level of intensification and more precisely of the N fertilization use during the grassland phase; and (iii) the analysis of the risk for peak of nitrate leaching after grassland re-cultivation as a consequence of a higher N mineralization. This experiment was carried out in France middle-west with a 9 year data base, comparing maize, wheat and barley crop rotation systems with different mixture pastures (*Festuca arundinacea, Lolium perenne* and *Dactylis glomerata*) cycle participation (0, 3, 6 and 20 years). We concluded that the introduction of mowed grassland sequences with this arable crop rotation leads to a strong reduction of the nitrate concentration of the ground water, the more proportion of grassland within the rotation the more NO_3^- concentration is reduced, whatever the level of N fertilization during the grassland sequence.

Keywords – drainage; leaching; nitrate; grazing; animal production.

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[1] Doctoral thesis in Animal Science, Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil. 130p. August, 2014

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LISTA DE ABREVIATURAS E SÍMBOLOS

ACBB	Agroecossistema, ciclos biogeoquímicos e biodiversidade
Al	Alumínio
C	Carbono
cm	Centímetro
$cmol_c$	Centimol de carga
CNPq	Centro Nacional de Pesquisa
DM	Dry matter
dm	Decímetro
EC	Comunidade europeia
ET^0	Evapotranspiração de referência
ETR	Evapotranspiração real
FAO	Food and Agriculture Organization
ha	Hectare
INRA	Institut National de Recherche Agronomique
kg	Quilograma
L	Litro
m	Metro
mg	Miligrama
mm	Milímetro
MOS	Matéria orgânica do solo
MS	Matéria seca
N	Nitrogênio
n	Número
NO_3^-	Nitrato
ºC	Graus celsius
P	Significância
PV	Peso vivo
r	Coeficiente de correlação
R^2	Coeficiente de determinação
RMSE	Desvio padrão
RS	Rio Grande do Sul
S	Sul
SIPA	Sistema integrado de produção agropecuária
SOERE	Systeme d'Observation et d'Experimentation sur le long terme pour la Recherche en Environnement
UE	Unidade Experimental
UFRGS	Universidade Federal do Rio Grande do Sul
W	Oeste

1. CAPÍTULO I

1.1 Introdução geral

1.2 Sistema integrado de produção agropecuária

1.3 Influência das pastagens na drenagem e lixiviação de nitrogênio

1.4 Histórico das áreas experimentais

1.5 Hipóteses de trabalho

1.6 Objetivos

1.1 INTRODUÇÃO GERAL

As pastagens desempenham papel fundamental na dinâmica da atmosfera e da hidrosfera, que por sua vez conduzem a impactos globais, bem como contribuem para a preservação da biodiversidade e para a produção de alimentos seguros (Lemaire et al., 2011). Dentre os benefícios das pastagens, segundo Mohamed Sallen & Fisher (1993) e Humphreys (1994), destacam-se: a manutenção das características físicas, químicas e biológicas do solo, o uso mais eficiente dos recursos ambientais e controle da poluição e a produção animal e vegetal. Quando manejadas corretamente, permitem maior rentabilidade e estabilidade, além do incremento no controle de plantas daninhas e a quebra de ciclos de pragas e doenças quando em rotação com cultivos. As pastagens também são fundamentais para a manutenção dos reservatórios de água em superfície e em profundidade (Steiner & Franzluebbers, 2009), a ciclagem de nutrientes (Steiner & Franzluebbers, 2009) e o sequestro de carbono (Hopkins & Holz, 2006).

Segundo Anghinoni et al. (2011), o sistema integrado de produção agropecuário (SIPA) é um raro sistema de produção onde o dilema produtividade *versus* conservação tem uma solução compatível com as atuais demandas da sociedade e do mercado consumidor. Utilizando as plantas de cobertura na alimentação animal, além da proteção do solo e do aproveitamento mais eficiente dos recursos ambientais, há aumento, equilibrado, nos níveis de produção animal e vegetal, consequentemente melhorando a renda do produtor e gerando um sistema de produção sustentável.

A agricultura é o maior contribuinte para a poluição nos reservatórios d’água (Addiscott et al., 1991; Guillemin & Roux, 1992; Datta et al., 1997; Townsend et al., 2003). Nos sistemas agrícolas, grande quantidade de nitrogênio (N) que permanece no solo é mineralizada após a colheita ou é lixiviada antes do estabelecimento da próxima cultura (Sapkota et al., 2012). Sobretudo, onde as precipitações excedem a capacidade de retenção do solo, lixiviando quantidades significativas de N (Pedersen et al., 2009). Vários trabalhos mostram que a utilização de plantas de cobertura reduz a lixiviação de nitrogênio em rotação com culturas de soja e milho (Tonitto et al, 2006; Kaspar et al, 2007; Dabney et al., 2011; Kaspar & Singer, 2011).

Este trabalho apresenta, a seguir, considerações sobre a produção animal e de soja em um SIPA. Após, são apresentadas algumas considerações sobre drenagem e lixiviação de nitrogênio. Esses dois trabalhos têm como ponto de ligação a pastagem, como fator diferencial nos sistemas de cultivos. No primeiro, visando o papel produtivo e conservacionista. No segundo, principalmente, a conservação ambiental. Em sequência, a hipótese e os objetivos dos dois estudos são apresentados. Nos capítulos posteriores (II e III) são abordadas a relação entre a produção vegetal (pasto e soja) e produção animal num SIPA de longa duração na região sul do Brasil; e a influência da introdução de pastagens na rotação de culturas e o tempo de permanência destas na rotação, no tocante a drenagem e lixiviação de nitrogênio. Finalmente, no capítulo IV, são apresentadas as conclusões gerais da tese.

1.2 Sistema integrado de produção agropecuária

Os sistemas integrados de produção agropecuária (SIPAs) oportunizam interações ecológicas entre os diferentes usos da terra tornando os ecossistemas agrícolas mais eficientes na ciclagem de nutrientes, preservando os recursos naturais e o meio ambiente, melhorando a qualidade do solo e aumentando a biodiversidade (Lemaire et al, 2014). Segundo Franzluebbers (2007), os SIPAs podem melhorar a robustez e produtividade dos sistemas agrícolas, reduzir a necessidade de insumos externos, aumentar a estabilidade econômica e a diversidade, além de reduzir a poluição ambiental vinda da agricultura.

As pastagens desempenham importante papel nos SIPAs não só como forragem para a produção animal sustentável, mas também como prestadora de serviços ecossistêmicos essenciais, como a absorção dos impactos ambientais negativos resultantes da intensificação da agricultura (Lemaire et al., 2005). Moraes et al. (2014) apresentam um levantamento de diversos trabalhos realizados em SIPAs na região sul do Brasil, que em sua grande maioria, obtiveram rendimentos das culturas anuais aumentados após a utilização de animais em pastejo.

Os SIPAs possuem potencial único para a intensificação da produção de alimentos de forma sustentável, mas esse potencial depende do manejo adequado dos animais no sistema (Moraes et al, 2014). O ponto chave no manejo dessas pastagens é definir quanto a intensidade de pastejo pode ser aumentada sem prejudicar os demais serviços ecossistêmicos prestados por ela. Neste sentido, a principal ferramenta de manejo da pastagem é a altura do pasto, que define, indiretamente, a produtividade animal (individual e por área), a produtividade do pasto e o resíduo remanescente após a saída dos animais.

O sucesso do SIPA está ligado a intensidade de pastejo empregada, pois ela é responsável pela variação na estrutura do pasto (altura e densidade, por exemplo) que, por sua vez, é a característica central e determinante na produtividade animal, eficiência e sustentabilidade do sistema de produção. Segundo Anghinoni et al. (2011), o efeito benéfico do SIPA, com pastejo em intensidades adequadas, decorre da melhor relação entre massa de raízes e parte aérea acumuladas, pois há mínimo revolvimento do solo e, portanto, pouca incorporação mecânica dos resíduos vegetais, diminuindo a oxidação. Além disso, segundo os mesmos autores, o que contribui para o acúmulo de matéria orgânica do solo (MOS) em profundidade é o transporte de resíduos vegetais da superfície do solo, pela macro e mesofauna, que é bastante superior em SIPA em relação aos puros.

1.3 Influencia das pastagens na drenagem e lixiviação de nitrogênio

A água subterrânea é uma das principais fontes de água potável em muitos países, e é frequentemente utilizada sem tratamento, particularmente em poços particulares (Jégo et al., 2008). Quantificar sua taxa atual de recarga é pré-requisito para a gestão eficiente e sustentável dos recursos hídricos subterrâneos. E segundo Vries et al. (2002), é chave para o desenvolvimento econômico de regiões que delas dependem para seu desenvolvimento.

Lerner et al. (1990) apresentam três principais processos de recarga das águas subterrâneas (Figura 1): 1) Recarga direta – água adicionada pelo excesso de umidade do solo por percolação vertical através da zona não saturada; 2) Recarga indireta: percolação através de cursos d'água superficiais; e 3) Recarga localizada: forma intermediária de recarga de água, resultante da concentração horizontal na superfície com ausência de canais bem definidos.

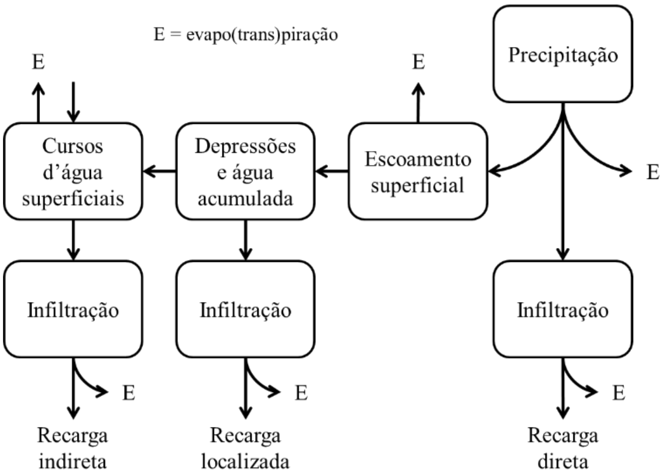


Figura 1. Mecanismos de recarga de água subterrânea. (Adaptado de Lerner, 1997).

Diversos fatores, e suas interações, influenciam na quantidade e na qualidade da água drenada para as reservas subterrâneas: condições climáticas, composição geológica, morfologia e condição do solo, além da vegetação (Vries et al., 2002; Premrov et al., 2012). Segundo esses autores, a percolação profunda em áreas úmidas é controlada principalmente pelo excedente da precipitação efetiva (chuva menos evapotranspiração potencial), a capacidade de infiltração do solo e a capacidade de armazenamento e transporte de sub-superfície.

A agricultura é a maior causadora da poluição por nitrogênio nas águas subterrâneas (Gustafson, 1983; Strebel et al., 1989; Addiscott et al., 1991; Datta et al., 1997; Townsend et al., 2003; Kvítek et al, 2009). Em função disto, a União Européia criou uma normatização (Nitrate Directive – 91/676/EEC) que controla e limita o teor de nitratos em 50 mg L^{-1} nos recursos hídricos superficial e subterrâneo. Na Europa, a lixiviação excessiva de nitratos para as reservas subterrâneas está associada com a agricultura intensiva, especialmente em sistemas onde o solo é deixado em pousio durante o inverno

(Neill, 1989). As menores precipitações que ocorrem no verão, associadas a elevada evapotranspiração, geralmente, são suficientes para restringir os períodos de drenagem nesta época do ano, permitindo o acúmulo de nitratos no solo, que poderá ser lixiviado com os eventos de drenagem que ocorrem no período de outono/inverno (Cuttle & Scholenfield, 1995).

Além dos fatores que interferem na drenagem da água, a lixiviação de nitrogênio é ligada ao sistema de cultura e às fertilizações utilizadas, ao manejo e características do solo, teor de matéria orgânica e a presença ou não de escoamento superficial (Shepherd et al., 2001; Oenema et al., 2005; Jégo et al., 2008; Kopacek et al., 2013).

As comparações dos níveis de nitrato lixiviado observados em diferentes sistemas de cultivo demonstram a relação entre o uso da terra e as concentrações médias de nitrogênio em fluxo de água (Kvítek et al., 2009). Uma das maneiras de diminuir a lixiviação de nitratos é a utilização de culturas de cobertura durante o período entre-culturas (Dabney et al., 2011; Kaspar & Singer, 2011; Kaspar et al., 2012). O levantamento realizado por Tonitto et al. (2006), com 69 trabalhos realizados nos USA, mostrou que plantas de cobertura (não leguminosas) reduziram em média 70% das perdas por lixiviação de nitratos e essa redução foi diretamente relacionada com o crescimento das culturas. As pastagens são capazes de absorver e utilizar maiores quantidades de nitrogênio que as culturas anuais, diminuindo as perdas por lixiviação (Whitehead, 1995). Estudos demonstram que houve aumento na área cultivada com pastagens em detrimento das culturas anuais com reduções significativas nos teores de nitrogênio lixiviado (Kvítek et al., 2009).

1.4 Histórico das áreas experimentais

1.4.1 Sistema integrado de produção agropecuária na Região sul do Brasil – Tupanciretã/RS

Este experimento vem sendo conduzido, desde 2001, em área pertencente à Fazenda do Espinilho, localizada no município de São Miguel das Missões - RS, região do Planalto Médio do RS. O solo é classificado como Latossolo Vermelho Distroférrico, que é caracterizado como profundo, bem drenado, com coloração vermelho-escura e textura argilosa (54% de argila). A área é cultivada no sistema plantio direto desde 1990, com uma mistura de aveia preta + azevém (*Avena strigosa* + *Lollium multiflorum*) no período de outono-inverno e soja (*Glycine max*), na primavera-verão. No outono de 2001, após a colheita da soja, foi efetuada amostragem do solo para sua caracterização física e química. O experimento teve início em maio desse mesmo ano, com a implantação das espécies de inverno: aveia preta (100 kg sementes ha^{-1}) e azevém (ressemeadura natural). A área total do experimento (Figura 2) é de aproximadamente 22 hectares, a qual foi dividida em 12 piquetes, cujos tamanhos variam de 0,8 a 3,6 hectares adicionadas de duas áreas de referência (sem pastejo) com, aproximadamente, 0,1 hectare cada, situadas entre os blocos.

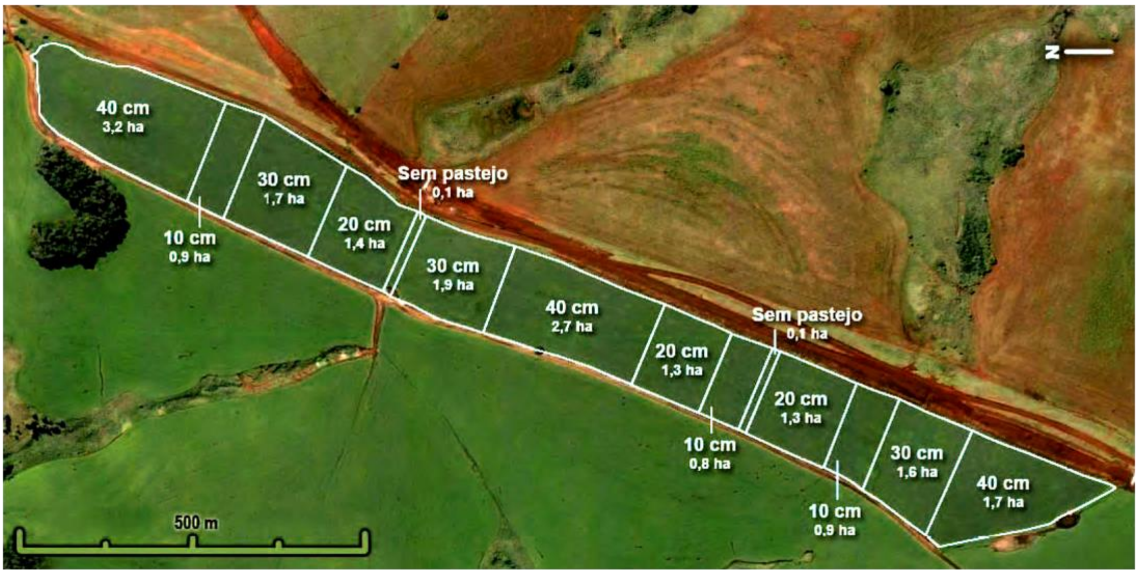


Figura 2. Croqui da área experimental na Fazenda do Espinilho.

Os tratamentos são diferentes alturas de manejo do pasto (10, 20, 30 e 40 cm) dispostos num delineamento experimental de blocos ao acaso, com três repetições, sendo a altura do pasto medida a cada 15 dias, pelo uso do método Sward stick (Barthram, 1986). As alturas de manejo do pasto são obtidas variando-se a carga animal, retirando-se ou colocando-se bovinos de corte em função da altura medida, estando esta abaixo ou acima, respectivamente, das alturas pretendidas. Como testemunhas sem pastejo, utilizam-se áreas entre os blocos, onde o pastejo não é permitido. Utilizam-se bovinos jovens, com idade ao redor de 12 meses, sem padrão racial definido, com peso vivo inicial de aproximadamente 200 kg. O método de pastoreio adotado é o contínuo, com início de pastejo na área quando o pasto atinge 20 cm de altura (aproximadamente, 2000 kg de MS ha^{-1}). Geralmente, o ciclo de pastejo é iniciado na primeira quinzena de julho, estendendo-se até a primeira quinzena de novembro.

Após o primeiro ciclo de pastejo e antecedendo a implantação do primeiro ciclo da soja (novembro de 2001), foram aplicadas, na superfície do solo de toda a área experimental, 4,5 Mg ha^{-1} de calcário (PRNT 62%), que corresponde à dose recomendada (CQFS RS/SC, 2004) para elevar o pH do solo até 5,5 na camada de 0 – 10 cm, na condição de plantio direto consolidado. Na área sem pastejo, algumas parcelas receberam calcário na dose equivalente ao restante do experimento (SP-4,5), enquanto outras permaneceram sem calcário (SP-0). A soja foi colhida em maio de 2002.

A partir do outono desse ano e até o presente momento, repetiu-se o mesmo procedimento de implantação da pastagem e pastejo com os animais, seguidos da implantação e condução da cultura da soja (Tabela 1). No outono de 2010, antecedendo ao pastejo, o calcário foi reaplicado na superfície do solo, em parte da área (600 m^2 dentro de cada parcela), na dose de 3,6 Mg ha^{-1}, novamente com o objetivo de elevar o pH do solo a 5,5 na camada de 0 – 10 cm, conforme CQFS RS/SC (2004).

No período experimental têm sido efetuadas avaliações periódicas do crescimento e da qualidade do pasto, do resíduo após pastejo, da carga animal utilizada para manter os tratamentos, do ganho individual e por área dos animais. Na soja, além do rendimento de grãos, tem sido determinada a quantidade dos resíduos remanescentes e determinados os componentes de rendimento de grão. Amostras de solo são retiradas para a avaliação de atributos físicos (densidade, porosidade, umidade e estado de agregação), em três camadas; mecânicos (resistência à penetração e compressibilidade), também em três camadas; e químicos (pH em água, matéria orgânica, fósforo e potássio disponíveis e cálcio, magnésio e alumínio trocáveis e capacidade de troca de cátions), em nove camadas. No terceiro e no nono anos foi também avaliada a qualidade de carcaça dos bovinos ao final do período de pastejo e no quarto ano foi avaliado o comportamento ingestivo dos animais. No quarto ano iniciou-se o trabalho na área de Mecanização Agrícola (Relação Solo-Máquina), para avaliar a eficiência de sulcadores de semeadoras de plantio direto nas diferentes condições de compactação do solo, e no sétimo ano, o estudo da variabilidade espacial de atributos químicos (indicadores de fertilidade do solo), físico (resistência à penetração) e mecânico (esforço de tração em hastes sulcadoras) e seu efeito no rendimento da soja**.** A partir do quarto ano, passou-se a estudar a ciclagem de nutrientes, especialmente a do carbono e do fósforo em suas respectivas formas, frações e disponibilidades e, ainda, o estado de agregação do solo em função dos diferentes aportes de resíduo da pastagem, da soja e dos animais e da adubação utilizada. Nos anos de 2009 a 2011 foi efetuado um estudo da decomposição dos resíduos (pasto, esterco e soja) e a cinética de liberação de nitrogênio, fósforo, potássio, cálcio e magnésio, visando à sua ciclagem no sistema.

A partir de 2011 começou-se a estudar as emissões de gases de efeito estufa pelo solo e pelos animais. Atualmente (2014), iniciaram-se estudos com bioacústica e com o deslocamento e utilização da pastagem pelos animais.

Tabela 1. Datas de semeadura e colheita da soja, proveniência do azevém, data de semeadura do pasto, datas de entrada e de saída dos animais e adubações aplicadas nos diferentes anos experimentais

Ano	Soja		Azevém[1]	Semeadura	Data		N[2]	P[3]	K[4]
	Semeadura	Colheita		do pasto	Entrada	Saída	(kg ha^{-1})		
2001	10/12/01	06/05/02	S	18/05	24/07	05/11	45	60	-
2002	17/12/02	01/05/03	S e RN	13/05	16/07	13/11	45	60	90
2003	12/12/03	07/05/04	S e RN	19/05	21/07	07/11	90	60	60
2004	05/12/03	30/04/05	S e RN	10/05	12/07	14/11	45	60	90
2005	05/12/04	05/05/06	S e RN	04/05	05/07	13/11	45	60	90
2006	02/12/05	12/05/07	S e RN	11/05	29/06	08/11	45	60	90
2007	15/12/06	17/05/08	S e RN	12/05	14/07	09/11	45	60	60
2008	18/12/07	24/04/09	RN	17/05	17/07	15/11	45	60	60
2009	26/12/08	17/04/10	RN	17/04	17/07	30/10	90	60	60
2010	27/11/10	26/03/11	RN	30/04	06/07	02/11	45	60	60
2011	16/11/11	16/04/12	RN	19/04	10/06	07/11	90	60	60

[1] S=semeado, RN=Ressemeadura natural; [2] Aplicado no pasto em forma de uréia; [3] e [4] Aplicado na soja em forma de P_2O_5 e K_2O, respectivamente.

1.4.2 Systeme d'Observation et d'Experimentation sur le long terme pour la Recherche en Environnement (SOERE)

O dispositivo experimental: Agro-ecossistemas, ciclos biogeoquímicos e biodiversidade (ACBB) foi implementado em 2003 por equipes do Institut National de Recherche Agronomique (INRA), com o apoio do Institut National des Sciences de l'Univers (INSU). Em 2011, passou a chamar-se Systeme d'Observation et d'Experimentation sur le long terme pour la Recherche en Environnement (SOERE – ACBB).

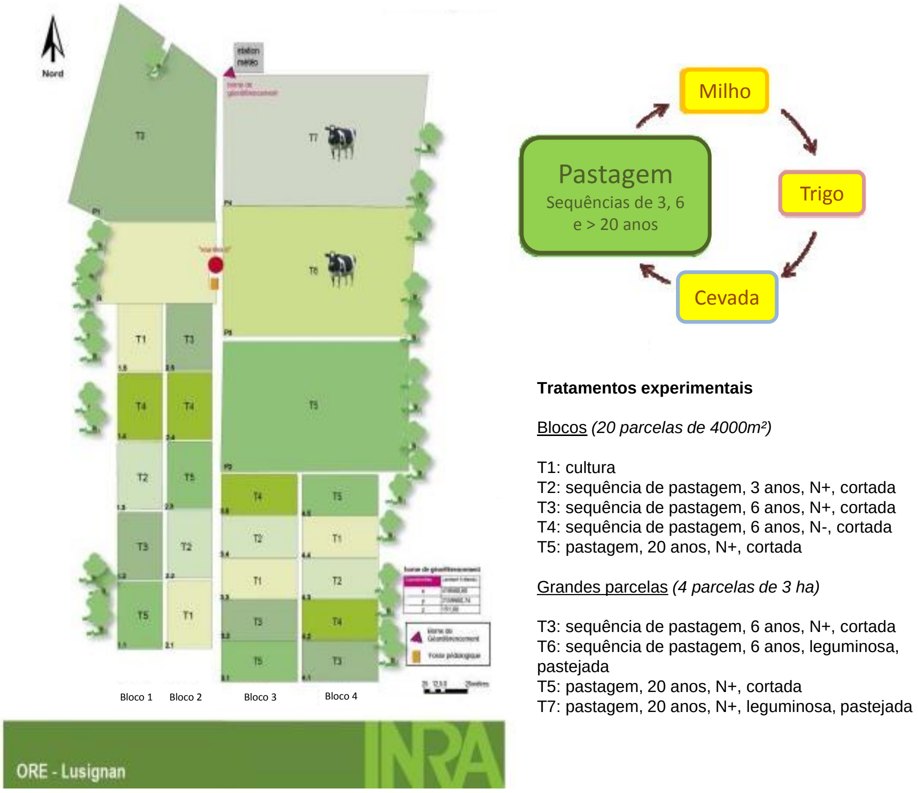
O SOERE-ACBB consiste num conjunto de três locais de teste dedicados ao estudo a longo prazo da dinâmica e evolução dos ecossistemas campestres sob a ação do homem e suas conseqüências sobre o meio ambiente. As alteração nas práticas de manejo dos ambiente produtivos (padrões de uso da terra e/ou práticas agrícolas) produzem efeitos sobre o ambiente. Esses efeitos são detectados em médio e longo prazo. Por outro lado, qualquer intervenção humana, para restaurar o meio ambiente, somente pode ser avaliada, após longo períodos de tempo.

O SOERE tem como objetivos analisar os processos para compreensão das trajetórias evolutivas no médio e longo prazo, mantendo esses dados disponíveis para toda a comunidade científica. Os assuntos principais avaliados pelo dispositivo são a água e a preservação do solo, o combate ao aquecimento global e a intensificação ecológica. Especificamente, o SOERE tem como objetivos quantificar o acúmulo de carbono e o seqüestro no solo em diferentes sistemas de pastagem, analisar o processamento, a translocação e o tempo de residência dos elementos nos vários componentes da MOS, quantificar os fluxos internos de carbono e nitrogênio entre os diferentes compartimentos do sistema, MOS, plantas, microbita, fauna do solo, quantificar e modelar os fluxos externos de C e N para a atmosfera e a hidrosfera.

O SOERE-ACBB é composto por três locais de experimentação:

- Pastagens temporárias, localizado em Lusignan/Poitou-Charentes, onde se avalia a dinâmica dos sistemas de rotação cultura/pastagem;
- Pastagens permanentes, em Theix e Laqueuille/Auverne, onde se aborda a dinâmica em pastagens naturais;
- Grandes culturas, situado em Mons/Picardie, onde se estuda a evolução dos sistemas de grandes culturas em diferentes níveis de perturbação do solo.

O dispositivo experimental de Lusignan, região de Poitou-Charentes, trabalha com sistemas de pastagens temporárias em rotação com culturas cerealistas (Figura 4). Os tratamentos são cinco períodos de duração da pastagem na rotação de culturas: zero, três, seis e vinte anos, com alta ou baixa adição de nitrogênio, com ou sem pastejo (Figura 5). As culturas em rotação são milho, trigo e cevada, e a pastagem é composta por uma mistura de festuca (*Festuca arundinacea cv* Soni), azevém perene *(Lolium perenne cv* Milca) e dactylis (*Dactylis glomerata cv* Ludac).



Tratamentos experimentais

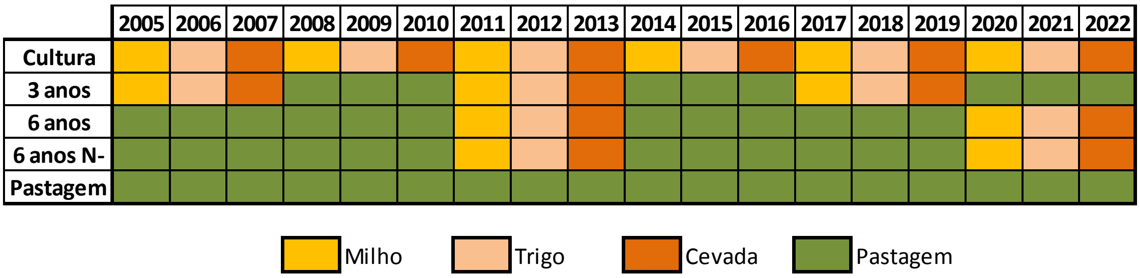
Blocos *(20 parcelas de 4000m²)*

T1: cultura
T2: sequência de pastagem, 3 anos, N+, cortada
T3: sequência de pastagem, 6 anos, N+, cortada
T4: sequência de pastagem, 6 anos, N-, cortada
T5: pastagem, 20 anos, N+, cortada

Grandes parcelas *(4 parcelas de 3 ha)*

T3: sequência de pastagem, 6 anos, N+, cortada
T6: sequência de pastagem, 6 anos, leguminosa, pastejada
T5: pastagem, 20 anos, N+, cortada
T7: pastagem, 20 anos, N+, leguminosa, pastejada

Figura 3. Dispositivo experimental SOERE-ACBB de Lusignan.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Cultura	🟨	🟫	🟧	🟨	🟫	🟧	🟨	🟫	🟧	🟨	🟫	🟧	🟨	🟫	🟧	🟨	🟫	🟧
3 anos	🟨	🟫	🟧	🟩	🟩	🟩	🟨	🟫	🟧	🟩	🟩	🟩	🟨	🟫	🟧	🟩	🟩	🟩
6 anos	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟫	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟫	🟧
6 anos N-	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟫	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟫	🟧
Pastagem	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

🟨 Milho 🟫 Trigo 🟧 Cevada 🟩 Pastagem

Figura 4. Sequência de culturas em cada tratamento.

Tabela 2. Variedades, datas de semeadura e colheita, fertilização nitrogenada (kg N ha^{-1}) e rendimento das culturas (milho, trigo e cevada: kg grãos ha^{-1}; pastagem: kg MS ha^{-1}) nos diferentes anos e tratamentos

	Ano	Cultura	Variedade	Semeadura	Colheita	Fert. N	Rendimento
Cultura	**2005**	Milho	Texxud	21/04	22/09/2005	117	2524
	2006	Trigo	Caphorn	24/10/2005	19/07/2006	85	6864
	2007	Cevada	Vanessa	26/10/2006	28/06/2007	120	4559
	2008	Milho	Anjou 387	07/05	17/10/2008	80	11638
	2009	Trigo	Caphorn	29/10/2008	16/07/2009	150	5898
	2010	Cevada	Vanessa	22/10/2009	06/07/2010	83	4235
	2011	Milho	PR38V12 PIONER	18/04	27/09/2011	72	7644
	2012	Trigo	Caphorn	16/11/2011	24/07/2012	160	5627
	2013	Cevada	Limpid	16/10/2012	16/07/2013	90	4638
3 anos	**2005**	Milho	Texxud	21/04/2005	22/09/2005	117	2577
	2006	Trigo	Caphorn	24/10/2005	19/07/2006	175	6825
	2007	Cevada	Vanessa	26/10/2006	28/06/2007	120	4443
	2008	Pastagem	Dactyles + Festuca + Azevém	17/09/2007	-	330	14204
	2009					230	10563
	2010					210	5690
	2011	Milho	PR38V12 PIONER	18/04/2011	27/09/2011	36	7704
	2012	Trigo	Caphorn	16/11/2011	24/07/2012	160	5443
	2013	Cevada	Limpid	16/10/2012	16/07/2013	90	4960
6 anos	**2005**	Pastagem	Dactyles + Festuca + Azevém	20/04/2005	-	0	0
	2006					170	10673
	2007					380	15873
	2008					330	12087
	2009					230	9592
	2010					210	5495
	2011	Milho	PR38V12 PIONER	18/04/2011	27/09/2011	36	8455
	2012	Trigo	Caphorn	16/11/2011	24/07/2012	160	5714
	2013	Cevada	Limpid	16/10/2012	16/07/2013	90	5170
6 anos N^-	**2005**	Pastagem		20/04/2005	-	0	0

	2006		Dactyles + Festuca + Azevém			30	5834
	2007					30	5929
	2008					30	4864
	2009					30	2543
	2010					30	1687
	2011	Milho	PR38V12 PIONER	18/04/2011	27/09/2011	36	7042
	2012	Trigo	Caphorn	16/11/2011	24/07/2012	160	5904
	2013	Cevada	Limpid	16/10/2012	16/07/2013	90	5677
Pastagem	**2005**	Pastagem	Dactyles + Festuca + Azevém	20/04/2005	-	0	0
	2006					170	11035
	2007					380	15531
	2008					330	12609
	2009					230	9173
	2010					210	5303
	2011					120	4436
	2012					210	5767
	2013					220	10690

1.5 HIPÓTESES DO TRABALHO

1. Diferentes alturas de manejo de pastos mistos de aveia e azevém, independentemente das características de ano, proporcionam um padrão de resposta na produção do pasto e na produção animal em um sistema integrado de produção agropecuária.
2. A presença de pastagem em rotação com culturas cerealistas reduz contaminação da água por nitrato devido à lixiviação de nitrogênio.

1.6 OBJETIVOS

Este trabalho teve por objetivo avaliar se existe padrão no comportamento das variáveis de produção animal e de pasto manejado sob diferentes alturas em SIPA, bem como definir metas de manejo de pastos mistos de aveia + azevém que beneficiem o desempenho animal e a conservação do sistema de produção. Um segundo objetivo foi avaliar o efeito de diferentes períodos de duração da pastagem em sistemas de rotação de cultura na drenagem e lixiviação de nitrogênio.

2. CAPÍTULO II

Sistema integrado de produção agropecuária: buscando padrões de resposta na produção de pasto e do animal em experimento de longo prazo[1]

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[1] Elaborado de acordo com as normas da Agriculture, Ecosystems and Environment (Apêndice 1).

Sistema integrado de produção agropecuária: buscando padrões de resposta na produção de pasto e do animal em experimento longo prazo

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Resumo – Sistemas integrados de produção agropecuária (SIPAs) promovem diversos benefícios ao sistema de cultivo e para o ambiente. No entanto, para que esses benefícios ocorram, é necessário assegurar práticas de manejo que permitam rendimento e conservação. Apesar de existirem resultados que indiquem quais são as intensidades de pastejo (alturas de manejo do pasto) que assegurem desempenho e conservação, estes resultados são pontuais e variáveis em decorrência dos efeitos de ano. Em função disto, utilizando uma base de 10 anos de dados (2001-2011), propomos neste trabalho analisar e investigar a existência de padrões no comportamento das variáveis de produção animal e de pasto manejado sob diferentes alturas em SIPA. Também propõe-se definir metas de manejo de pastos mistos de aveia + azevém que beneficiem o desempenho animal e a conservação do sistema de produção. O SIPA é composto de pastagem mista de aveia preta x azevém durante o período hibernal com pastoreio contínuo e soja durante o período estival. Os tratamentos são quatro alturas do pasto (10, 20, 30 e 40 cm), que definem diferentes intensidades de pastejo. A variação na altura real do pasto aumentou com o aumento na altura pretendida. As variáveis de produção animal e de pasto estudadas são afetadas pelas condições climáticas anuais, no entanto, existe padrão nas relações entre produção animal e de pasto ao longo dos 10 anos de experimento. A altura de manejo do pasto de 30 cm permite o acúmulo de resíduo sobre o solo, que beneficia o SIPA, e que proporciona crescimento do pasto e ganho animal satisfatório e estável ao longo dos anos.

Palavras-chave: altura do dossel, conservação, experimento de longo prazo, plantio direto, sustentabilidade.

1. Introdução

Sistemas integrados de produção agropecuária (SIPAs) promovem interações ecológicas entre os diferentes componentes do ecossistema produtivo, tornando-os mais eficientes na ciclagem de nutrientes, preservando os recursos naturais e o meio ambiente, melhorando a qualidade do solo e aumentando a biodiversidade (Lemaire et al., 2014). Para que isso ocorra, é necessário assegurar práticas de manejo conservacionistas, como o plantio direto. Os benefícios da presença de resíduos sobre o solo já foram amplamente discutidos internacionalmente (Franzluebbers, 2007; Franzluebbers and Stuedemann, 2007, 2008, 2014; Fernandéz et al, 2010).

No caso do sul do Brasil, um dos arranjos de SIPA mais utilizados é o cultivo de soja durante o verão e produção de bovinos de corte em pastagens de aveia e azevém no período de inverno (Anghinoni et al., 2013). Este sistema tem apresentado maior retorno econômico quando comparado ao cultivo exclusivo da soja (Oliveira et al., 2013). No entanto, para o sucesso do sistema, é necessário adequar a intensidade de pastejo de forma que concilie bons rendimentos de produção animal e da produção de soja, e que permita quantidade de resíduo suficiente para o sistema plantio direto.

Alguns trabalhos demonstram que a altura de manejo que maximiza a produção animal em pastos mistos de aveia e azevém ou azevém solteiro está entre 20 e 30 cm (Aguinaga et al., 2006; Lopes et al., 2008; Amaral et al., 2012; Kunrath et al., 2014). Apesar de existirem resultados que indiquem que essas alturas promovem melhor desempenho animal, estes resultados são pontuais e variáveis em decorrência dos efeitos de ano pelas condições climáticas.

Dessa forma, para este trabalho, utilizamos uma base de dados de dez anos, uma vez que experimentos de longa duração aumentam a confiabilidade na interpretação dos resultados (Rasmussen et al, 1998), objetivando i) analisar e investigar se existe padrão no comportamento das variáveis de produção animal e de pasto manejado sob diferentes alturas em SIPA e ii) definir metas de manejo de pastos mistos de aveia + azevém que beneficiem o desempenho animal em SIPAs.

2. Material e Métodos

2.1 Localização, caracterização e histórico da área experimental

A área experimental vem sendo conduzida sob sistema integrado de produção agropecuária (SIPA) desde 2001 em parceria público-privada entre os departamentos de Solos e de Plantas Forrageiras e Agrometeorologia da Universidade Federal do Rio Grande do Sul (UFRGS) com a Cabanha Cerro Coroado. A área está localizada na Fazenda do Espinilho, no município de São Miguel das Missões (28°56' S 54°20' O). O clima caracteriza-se como subtropical úmido e quente (Cfa) segundo a classificação de Köppen (Kottek et al., 2006), com temperatura média anual de 19°C e precipitação média anual de 1850 mm (Matzenauer et al., 2011). O relevo é ondulado a suavemente ondulado com altitude média de 465 m. A temperatura média e a precipitação ocorrida no período invernal (maio à outubro) foram coletadas da Estação Meteorológica do Município de São Luiz Gonzaga, mantida pelo Instituto Nacional de Meteorologia (Figura 1), situada a 70 km da área experimental.

O solo é classificado como Latossolo Vermelho distroférrico (EMBRAPA, 2006) da unidade de mapeamento Santo Ângelo (Streck et al., 2008), profundo, bem drenado, com coloração vermelho-escura e textura muito argilosa (0,54, 0,17 e 0,29 kg kg^{-1}, de argila, silte e areia, respectivamente). A área era cultivada em sistema plantio direto desde 1993 com aveia preta (*Avena strigosa* Schreb) no outono-inverno (maio a novembro) e soja (*Glycine max*) na primavera-verão (novembro a maio). Em novembro de 2000, foi realizada a caracterização química inicial do solo: 10,5 mg dm^{-3} de fósforo, 94 mg dm^{-3} de potássio, 3,2 cmol$_c$ dm^{-3} de Al^{+3}, 34 g kg^{-1} de matéria orgânica e pH de 4,3 (Cassol, 2003). Em abril de 2001, a área foi semeada com pasto misto de aveia preta x azevém (*Lolium multiflorum*) e utilizada para o pastejo de animais pela primeira vez, dando início ao sistema integrado de produção agropecuária.

2.2 Tratamentos e delineamento experimental

A área total experimental é de 22 ha, dividida em piquetes que variam de 0,8 a 3,6 ha. O SIPA é composto de pastagem mista de aveia preta x azevém durante o período hibernal com pastejo contínuo e soja durante o período estival. Os tratamentos são quatro alturas de manejo do pasto (10, 20, 30 e 40 cm), que definem diferentes intensidades de pastejo. O delineamento experimental é de blocos casualizados com três repetições, totalizando 12 piquetes (unidades experimentais – UE).

2.3 Período experimental e manejo do SIPA

Foi utilizada uma base de dados de 10 anos do período hibernal (2001 – 2011) de um SIPA típico da região Sul do Brasil. O manejo experimental foi o mesmo entre os anos. A data média de semeadura do pasto foi 08 de maio, de entrada dos animais nas UEs foi 09 de julho e de saída dos animais em 08 de novembro (para maiores detalhes, vide Oliveira et al., 2013). Foram aplicados no pasto 45 kg N ha^{-1}, na forma de ureia, anualmente, em dose única aos 40 dias após a semeadura. Nos anos de 2003, 2009 e 2011, foram aplicados 90 kg N ha^{-1} em duas doses, sendo a 1ª dose 30 dias após a semeadura e 2ª dose 15 dias antes do início do pastejo.

Em todos os anos a aveia-preta foi semeada em linha e o azevém, além da ressemeadura natural, foi semeado a lanço, excetuando-se os anos de 2008 à 2010 em que o azevém foi proveniente exclusivamente de ressemeadura natural. O monitoramento dos tratamentos foi realizado quinzenalmente, medindo-se 100 pontos de altura do pasto por unidade experimental com o método do bastão graduado (*sward stick*), proposto por Barthram (1985). Para manter as alturas pretendidas foram realizados ajustes na taxa de lotação animal com intervalos de 15 dias, com entradas ou saídas de animais conforme a metodologia de pastoreio contínuo com taxa de lotação variável proposta por Mott and Lucas (1952). Três animais-teste por piquete eram mantidos, com número variável de animais reguladores. Por ocasião do início do pastejo, a altura média do pasto e a massa de forragem nos anos avaliados foi 23,2 ± 3,9 cm e 1595,4 ± 709,5 kg MS ha^{-1}, respectivamente. O peso inicial médio dos animais para os 10 anos foi 203,0 ± 13,2 kg.

2.4 Avaliações no pasto

Nos pastos foram avaliadas: massa de forragem (kg de matéria seca (MS) ha^{-1}), taxa de crescimento diário do pasto (kg de MS ha^{-1}) e produção total de pasto (kg de MS ha^{-1}). A estimativa da massa de forragem foi realizada a cada 28 dias, utilizando-se a técnica de dupla amostragem (Wilm et al., 1944). Foram realizados cinco cortes aleatórios de forragem por UE. Nesses mesmos locais foram medidos cinco pontos de altura do pasto com o "*sward stick*", para posterior ajuste da massa de forragem em função da altura real do pasto, por meio da equação de regressão: $\hat{y}_i = b_0 + b_1 x_i$. A taxa de crescimento diário foi monitorada a cada 28 dias utilizando-se três gaiolas de exclusão ao pastejo por piquete, empregando a técnica descrita por Klingman et al.

(1943). A massa de forragem dentro e fora da gaiola foi obtida pela média dos cortes avaliados, em cada piquete. Todos os cortes foram realizados acima do mantilho, em área de 0,25m^2. As amostras foram secas em estufa de circulação forçada de ar a 60ºC, até peso constante. A produção total de pasto foi estimada pelo somatório da massa de forragem inicial com as produções dos sub-períodos (taxa de acúmulo x número de dias do sub-período). No último período de amostragem, após a saída dos animais, realizou-se avaliação para quantificar o resíduo (kg de MS ha^{-1}) nos diferentes tratamentos. Foi recolhido todo o material existente sobre o solo nos mesmos pontos utilizados para os cortes de massa de forragem. O resíduo foi determinado pelo somatório da massa de forragem final (saída dos animais) com o material que permaneceu sobre o solo.

2.5 Avaliações animais

Foram avaliados o ganho médio diário individual (kg de peso vivo (PV) dia^{-1}) e o ganho por área (kg PV ha^{-1}). O ganho por área foi calculado pela média do ganho individual dos três animais teste multiplicada pelo número de animais-dia e pela área total do piquete. A carga animal do período de pastejo, também expressa em kg de PV ha^{-1}, foi calculada pela adição do peso médio dos animais-teste com o peso médio de cada animal regulador, multiplicado pelo número de dias que estes permaneceram na pastagem, dividido pelo número total de dias de pastejo. Para todas as estimativas, os animais foram pesados com jejum de sólidos e líquidos de 12 horas.

2.6 Análises estatísticas

Os dados foram analisados mediante analise de variância e de contrastes, seguindo o modelo que integra os efeitos simples do ano e dos tratamentos e sua interação. Para tanto, os anos foram considerados aleatórios no modelo.

Assim, a normalidade dos dados foi testada pelo teste de Kolmogorov-Smirnov ($P>0,05$). Após esta análise, os resultados foram submetidos à análise de homogeneidade de variâncias (Levene’s Test) em nível de 5% de significância, para que se pudesse determinar se os diferentes anos deveriam ser avaliados de forma conjunta ou independentes.

Para as variáveis em que a análise de homogeneidade de variâncias apresentou interação dos efeitos de ano e tratamento ($P<0,05$), sinalizando que as análises deveriam ser realizadas independentemente a cada ano, foram realizadas análises de comparação entre os tratamentos nos anos avaliados e sua interação (ano*tratamento), modelando a heterocedasticidade. Para isso foi realizada uma análise de variância com 5% de significância para comparação das alturas de pastejo (tratamentos). As variáveis que apresentaram diferenças significativas tiveram suas médias comparadas pelo Teste de Tukey com o mesmo nível de significância.

Com a intenção de analisar e investigar a existência de padrão no comportamento das variáveis resposta, foram realizadas análises de correlação de Pearson e regressão até segunda ordem para as variáveis-resposta segundo valores de altura real do pasto. Para as análises de regressão, o ano foi considerado como variável aleatória. Sempre que a função-resposta foi significativa ($P<0,05$), optou-se por apresentar os resultados pela equação de regressão de maior coeficiente de determinação (R^2). Os dados foram analisados pelo aplicativo SAS (2002).

3. Resultados

As alturas médias reais (Figura 2) se mantiveram próximas às alturas propostas como tratamentos. A variação na altura real do pasto aumentou com o aumento na altura proposta. As médias foram de 12,1±1,89 cm; 20,9±3,02 cm; 30,1±3,81 cm e 37,8±4,92 cm, respectivamente para os tratamentos 10, 20, 30 e 40 cm de altura do pasto.

3.1 Produção do pasto

A massa de forragem inicial, na média de todos os anos analisados, apresentou diferença ($P=0,0375$) entre as alturas de manejo de 10 e 40 cm (1502 e 1667 kg MS ha^{-1}, respectivamente). Porém, não houve diferença na interação entre tratamento*ano ($P=0,1186$), sendo a massa de forragem inicial semelhante entre as diferentes alturas de pastejo em cada ano.

Houve interação ($P<0,0001$) entre as alturas de manejo e os anos avaliados para a massa de forragem (Tabela 1). A massa de forragem é incrementada em 87 kg MS ha^{-1} para cada centímetro na altura, segundo ajuste linear observado com a altura real do pasto (Figura 3).

A taxa de crescimento do pasto (Tabela 1) sofreu influência do ano de avaliação ($P<0,0001$), variando de 30,8 kg MS $ha^{-1}dia^{-1}$ em 2010 até 61,2 kg MS $ha^{-1}dia^{-1}$ em 2003 e, também, dos tratamentos ($P=0,0427$). A produção total de matéria seca (Tabela 1) apresentou diferença entre as alturas de manejo ($P=0,0006$) e entre os anos avaliados ($P<0,0001$), mas não houve interação entre os dois fatores ($P=0,0797$).

Houve interação ($P=0,0073$) entre anos e alturas de manejo do pasto (Tabela 1)para o resíduo final de matéria seca. Quando plotados todos os anos e avaliados conjuntamente (Figura 4), o resíduo apresentou comportamento linear em função das alturas de manejo do pasto ($\hat{Y}=166,2x$; $P<0,0001$; $R^2=0,9004$; $RMSE=654,2$; $n=84$), aumentando em 166 kg MS ha^{-1} para cada centímetro aumentado na altura do pasto.

3.2 Produção animal

A carga animal utilizada para manter as alturas de manejo desejadas respondeu de forma linear às alturas de manejo (Figuras 4 e 5), decrescendo com o aumento da altura. Houve interação entre ano e alturas de manejo (P<0,0001; Tabela 2).

O ganho individual diário dos animais seguiu uma regressão quadrática em função das alturas de manejo do pasto (P<0,0001), tendo como ponto máximo 33 cm de altura (Figura 5). O ganho por área ajustou-se a uma regressão linear (P<0,0001), diminuindo 11 kg PV ha^{-1} a cada centímetro aumentado na altura de manejo do pasto (Figura 5).

4. Discussão

A variação observada nas alturas reais de manejo pode causar imprecisões nas respostas aos tratamentos, uma vez que as alturas de dois tratamentos se transpassam (Figura 2). Isso ocorre, principalmente, nas maiores alturas (30 e 40 cm). Essas variações na altura real também podem ser observadas no gráfico que demonstra a relação com o ganho por área (Figura 5), onde observamos que as alturas reais dos tratamentos 30 e 40 cm variam de 25 a 40 cm e de 30 a 50 cm, respectivamente.

A diferença na massa de forragem inicial entre a altura de manejo 10 cm e a altura de manejo de 40 cm pode ser explicada pela menor densidade de plantas de azevém. Como essas plantas são provenientes de ressemeadura natural, com o aumento da intensidade de pastejo (diminuição da altura do pasto) há diminuição do banco de sementes do solo (Barth Neto et al., 2014). A densidade de plantas também corrobora para as diferenças ocorridas na massa de forragem (Figura 3). A relação apresentada entre a massa de forragem e a altura de manejo é semelhante a outros trabalhos (Carvalho et al., 2010, Kunrath et al, 2014). Essas duas variáveis apresentam relação consistente (P<0,0001 r=0,86). Um modelo confiável pode ser gerado por essa relação entre altura e massa de forragem. Isso se faz importante na medida que as avaliações de massa de forragem são destrutivas e ocorrem frequentemente. Esse modelo poderia auxiliar na predição da massa de forragem diminuindo a quantidade e frequência destas avaliações. Apesar das diferenças climáticas entre os anos, a massa de forragem aparenta sofrer menor influência que a produtividade animal.

A taxa de crescimento do pasto variou entre os anos em função das diferenças climáticas (precipitação, temperatura e radiação) ocorridas. As diferenças anuais são mais difíceis de serem explicadas, pois além das diferenças climáticas existem, ainda, as diferenças no comportamento das alturas ao longo do ciclo, as diferenças na adubação nitrogenada e a interação entre esses fatores. As diferentes alturas de manejo possibilitam diferentes quantidades de áreas foliares, responsáveis pela captação da energia solar (Taiz and Zeiger, 2009), influenciando a taxa de crescimento do pasto. Porém, essas diferenças não são limitantes mesmo para a menor altura de manejo (10 cm), uma vez que a taxa de crescimento é semelhante às alturas de 20 e 30 cm.

A produção total de pasto obteve o mesmo comportamento da taxa de crescimento, uma vez que é calculada a partir dessa variável. No entanto, as diferenças entre os tratamentos são melhor evidenciadas (Tabela 1). A produção de pasto é menor nas alturas de manejo de 10 e 20 cm em consequência das menores taxas de crescimento e da menor massa de forragem inicial, enquanto que nos tratamentos 30 e 40 cm as produções são maiores em função dos mesmos fatores serem superiores para essas alturas de manejo.

O resíduo é uma das variáveis mais importantes de um SIPA. Ele é que faz a ligação entre o ciclo de inverno e a cultura de verão, pois possui papel fundamental na proteção do impacto físico do casco do animal minimizando o adensamento e a compactação do solo (Flores et al., 2007; Franzluebbers and Stuedemann, 2008) e na diminuição da erosão do solo (Franzluebbers et al., 2012). Os principais fatores que afetam a quantidade de resíduo são, principalmente, a altura de manejo (r=0,82, P<0,0001), massa de forragem (r=0,93, P<0,0001) e a carga animal (r=-0,84, P<0,0001) utilizada para a manutenção dessa altura.

Oliveira et al. (2013), trabalhando com a mesma base de dados deste trabalho, não observaram diferença no rendimento da cultura de soja entre as áreas pastejadas e a testemunha sem pastejo. Esse resultado indica que a presença de animais em pastejo no inverno não prejudica o desenvolvimento da cultura de soja no verão, como já havia sido demonstrado por trabalhos anteriores (Cassol, 2003; Flores et al., 2007). Em levantamento realizado por Moraes et al. (2014), analisando diversos trabalhos em SIPA, demonstrou que a presença do animal em pastejo melhora significativamente as produções da diversas culturas em sequência ao pastejo. Além disso, a presença de animais em SIPAs proporciona aumento no retorno financeiro para os produtores (Franzluebbers and Stuedemann, 2007, Oliveira et al., 2013).

O ganho individual sofre influência da altura de manejo do pasto (P<0,0001 r=0,47) e da carga animal utilizada para a manutenção destas alturas (P<0,0001 r=-0,61). As alturas de manejo de 30 e 40 cm são semelhantes entre si e entre todos os anos avaliados. As diferenças são percebidas, geralmente, entre a maior intensidade de pastejo (10 cm) e as demais alturas. O ganho por área sofre as mesmas influências que o ganho individual pela altura de manejo e pela carga animal ($P<0,0001$ $r=-0,84$ e $r=0,89$, respectivamente), e também da massa de forragem ($P<0,0001$ $r=-0,78$). No entanto, o ganho por área aumenta com a diminuição na altura de manejo do pasto. Tendo em vista que o ganho individual apresenta comportamento quadrático e o ganho por área linear negativo deve-se, portanto, buscar uma altura de manejo que otimize o ganho individual (em torno de 30 cm, como demonstrado pela Figura 5) sem penalizar o ganho por área.

A altura de manejo é a chave central na produtividade do sistema. Em função da altura que definimos como meta, seremos responsáveis pela carga animal utilizada ($P<0,0001$ $r=-0,86$) e pela massa de forragem disponível para esses animais, pela produtividade animal do sistema e, ainda, pela manutenção dos resíduos sobre o solo e todos os benefícios que isso acarreta ao sistema de produção (físicos, químicos, biológicos e ambientais).

5. Conclusão

As variáveis de produção animal e de pasto estudadas são afetadas pelos anos experimentais, no entanto, existe um padrão nas relações entre produção animal e de pasto ao longo dos 10 anos de experimento sob sistema integrado de produção agropecuária.

A altura de manejo do pasto de 30 cm permite o acúmulo de resíduo sobre o solo e proporciona ganho animal satisfatório e estável ao longo dos anos.

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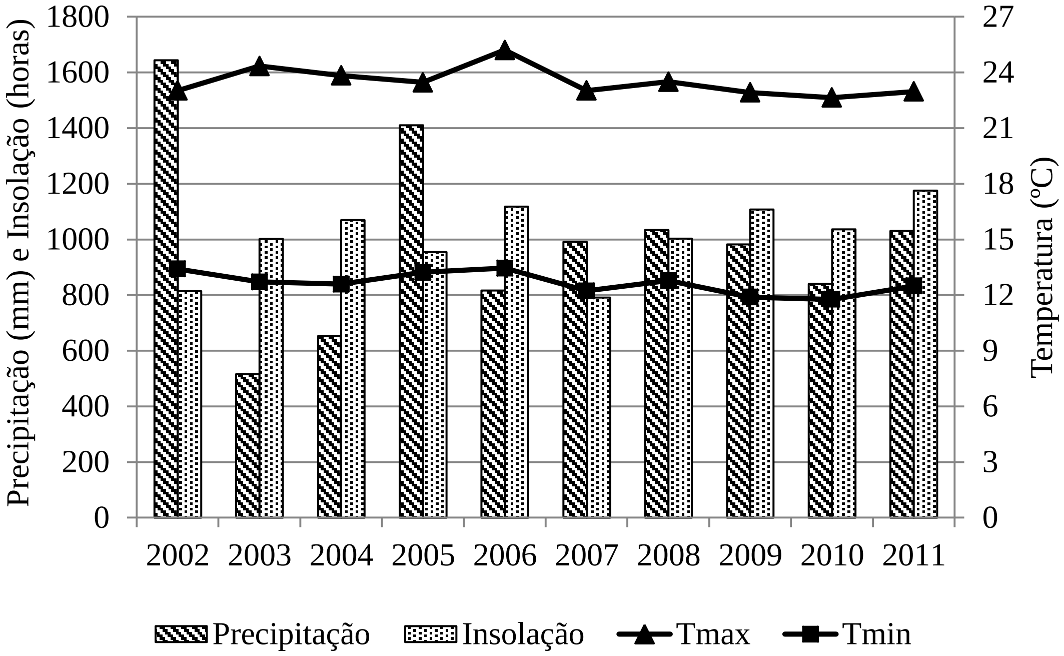

Figura 1. Precipitação, insolação, temperatura média máxima e temperatura média mínima do ar ocorridas entre a semeadura do pasto e a saída dos animais em cada ano experimental (as datas são encontradas em Oliveira et al., 2013). Fonte: INMET – Estação Meteorológica do Município de São Luiz Gonzaga).

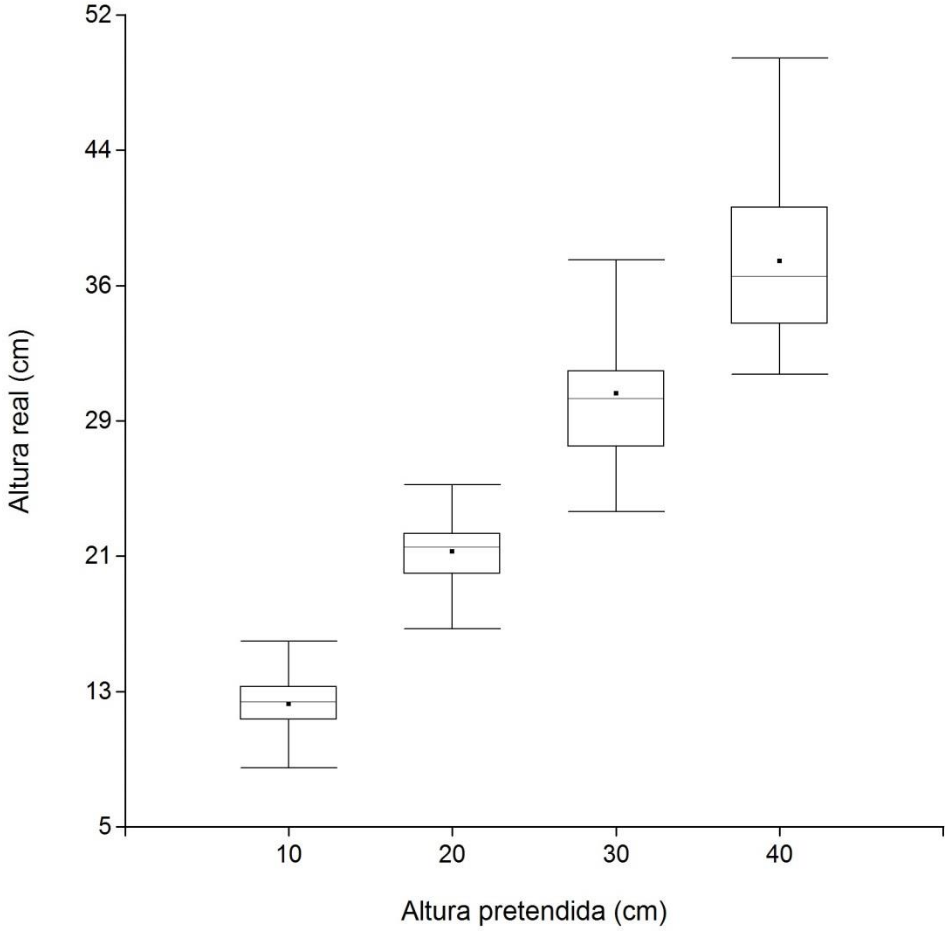

Figura 2. Relação entre alturas pretendidas e alturas reais de pasto misto de aveia + azevém obtidas ao longo de 10 anos de experimento sob sistema integrado de produção agropecuária.

Tabela 1. Massa de forragem, taxa de crescimento, produção total e resíduo de pasto misto de aveia + azevém em função das alturas de manejo e dos anos avaliados sob sistema integrado de produção agropecuária

	Altura do pasto				**Média***
	10 cm	**20 cm**	**30 cm**	**40 cm**	
Massa de forragem (kg MS ha^{-1})					
2001	1644 C abc	2632 B abc	3729 A ab	4015 A a	*3005*
2002	1328 C abcd	2159 B abcd	3104 A bc	3551 A abc	*2535*
2003	1901 C ab	2868 B a	4137 A a	4123 A a	*3257*
2004	1508 B abcd	1893 B de	2750 A cd	3254 A bc	*2352*
2005	1940 C a	2740 B ab	3417 AB abc	3974 A ab	*3018*
2006	1244 C abcd	1912 C cd	2972 B c	3921 A ab	*2512*
2008	1130 C cd	1931 B cd	2798 A cd	2917 A c	*2194*
2009	1193 C bcd	1983 B cd	2707 AB cd	3283 A bc	*2291*
2010	919 C d	1173 C e	2090 B de	3007 A c	*1797*
2011	949 C cd	1917 B bcd	2132 B e	2975 A c	*1993*
Média*	*1376*	*2142*	*2962*	*3502*	
Taxa de crescimento do pasto (kg MS ha^{-1} dia^{-1})					
2001	46,2	47,5	52,6	49,3	*48,9 ab*
2002	35,3	43,7	46,7	32,6	*39,6 bc*
2003	56,0	60,8	62,6	65,4	*61,2 a*
2004	41,4	51,7	47,8	49,7	*47,7 ab*
2005	64,1	32,2	44,0	46,2	*46,6 b*
2006	35,9	36,2	35,2	50,3	*39,4 bc*
2008	50,7	43,1	41,7	48,9	*46,1 b*
2009	33,6	43,2	56,5	64,1	*49,4 ab*
2010	18,3	23,5	33,4	47,6	*30,8 c*
2011	33,4	42,1	33,4	40,8	*37,4 bc*
Média*	*41,5 B*	*42,4 B*	*45,4 AB*	*49,5 A*	
Produção total de pasto (kg MS ha^{-1})					
2001	6616	6644	7330	6711	*6825 bcd*
2002	6062	6718	7542	6441	*6691 cd*
2003	9144	10174	10428	10002	*9937 a*
2004	8877	8144	7869	7756	*8161 bc*
2005	9213	7269	8601	7758	*8210 b*
2006	5835	6039	5945	7897	*6429 de*
2008	2442	3316	3810	4517	*3521 f*
2009	4762	5949	7511	8505	*6681 cd*
2010	3376	4170	5558	7514	*5155 e*
2011	5003	7016	5365	6913	*6074 de*
Média*	*6133 C*	*6544 BC*	*6996 AB*	*7401 A*	
Resíduo (kg MS ha^{-1})					
2001	1501 C a	3544 B ab	6320 A a	6565 A a	*4486*
2002	1727 C a	3820 B ab	4917 AB abc	5527 A ab	*3998*
2005	2363 B a	4306 A a	5774 A ab	6167 A ab	*4652*
2008	1239 C a	2410 BC bc	3779 AB cd	4765 A b	*3048*
2009	1330 C a	3245 B ab	4636 AB bcd	6545 A ab	*3864*
2010	812 B a	1551 B c	3387 A cd	4951 A ab	*2675*
2011	980 C a	3115 B abc	3151 B d	4855 A b	*3025*
Média*	*1422*	*3147*	*4561*	*5582*	

*Letras maiúsculas diferentes demonstram diferença estatística na coluna (alturas de manejo) pelo teste de Tukey ($P<0,05$), enquanto que letras minúsculas demonstram diferenças na linha (ano).

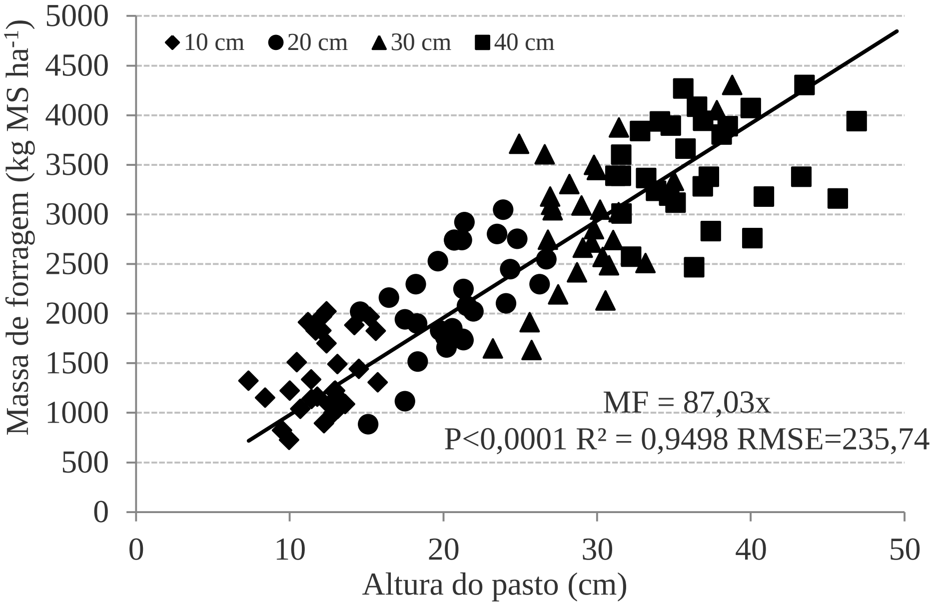

Figura 3. Relação entre massa de forragem e altura real de pasto misto de aveia + azevém ao longo de 10 anos de experimento sob sistema integrado de produção agropecuária.

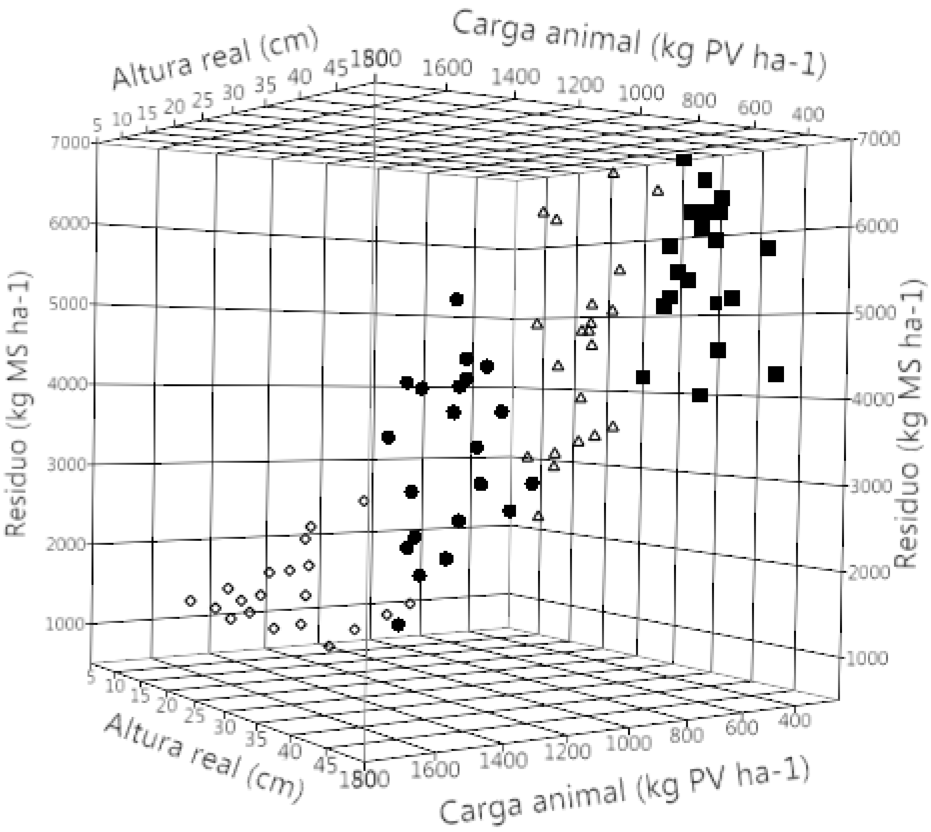

Figura 4. Relação entre carga animal, altura real de manejo e resíduo final de pasto misto de aveia + azevém obtidos ao longo de 10 anos de experimento sob sistema integrado de produção agropecuária. (Símbolos diferentes representam diferentes alturas de manejo do pasto: 10 cm (◊), 20 cm (●), 30 cm (Δ) e 40 cm (■)).

Tabela 2. Carga animal, ganho individual médio diário dos animais e ganho por área em pastos mistos de aveia + azevém em função das alturas de manejo e dos anos avaliados sob sistema integrado de produção agropecuária

	Altura do pasto				**Média***
	10 cm	**20 cm**	**30 cm**	**40 cm**	
	Carga animal (kg PV ha^{-1})				
2001	1359 A abcd	833 B bc	548 C a	292 C a	*758*
2002	1194 A cd	935 A abc	513 B a	304 B a	*736*
2003	1563 A a	1173 B a	661 C a	333 D a	*932*
2004	1280 A abcd	955 B abc	607 C a	397 C a	*810*
2005	1084 A de	792 B bc	477 C a	315 C a	*667*
2006	1431 A abc	933 B abc	608 C a	300 D a	*818*
2007	1210 A bcd	1051 A ab	746 B a	345 C a	*838*
2008	1387 A abc	914 B abc	678 B a	389 C a	*841*
2009	1492 A ab	893 B abc	696 B a	364 C a	*861*
2010	1182 A cde	917 AB abc	643 B a	348 C a	*773*
2011	902 A e	752 AB c	579 BC a	357 C a	*647*
Média*	*1280*	*923*	*614*	*340*	
	Ganho individual (kg PV dia^{-1})				
2001	0,89 A ab	1,03 A ab	1,11 A a	1,09 A a	*1,03*
2002	0,92 A ab	1,21 A a	1,19 A a	1,07 A a	*1,10*
2003	0,86 B b	1,01 AB ab	1,14 A a	1,12 A a	*1,03*
2004	0,85 B b	1,14 A ab	1,24 A a	1,21 A a	*1,11*
2005	0,76 A ab	1,24 A a	1,13 A a	1,10 A a	*1,11*
2006	0,76 B ab	1,05 AB ab	1,08 AB a	1,15 A a	*1,01*
2007	0,69 A b	1,02 A ab	0,95 A a	1,00 A a	*0,96*
2008	0,74 A b	0,94 A ab	0,97 A a	0,92 A a	*0,89*
2009	0,83 A ab	0,89 A b	0,96 A a	1,10 A a	*0,94*
2010	0,66 B b	1,01 AB ab	1,17 A a	1,15 A a	*1,02*
2011	0,96 AB a	0,82 B b	1,21 AB a	1,23 A a	*1,05*
Média*	*0,85*	*1,03*	*1,10*	*1,11*	
	Ganho por área (kg PV ha^{-1})				
2001	480 A abc	311 B d	273 BC a	121 C a	*296*
2002	541 A ab	537 A a	301 B a	154 B a	*383*
2003	540 A ab	440 A abcd	268 B a	153 B a	*350*
2004	530 A ab	490 A abc	321 B a	202 b a	*386*
2005	515 A abc	385 AB bcd	288 BC a	167 C a	*339*
2006	612 A a	496 A ab	328 B a	175 C a	*403*
2007	428 A bc	501 A ab	356 A a	185 B a	*368*
2008	495 A abc	419 AB abcd	282 BC a	156 C a	*338*
2009	529 A ab	390 AB abcd	337 B a	178 C a	*359*
2010	356 A c	375 A bcd	318 AB a	175 B a	*306*
2011	459 A bc	343 AB bc	324 AB a	230 B a	*339*
Média*	*499*	*426*	*309*	*172*	

*Letras maiúsculas diferentes demonstram diferença estatística na coluna (alturas de manejo) pelo teste de Tukey (P<0,05), enquanto que letras minúsculas demonstram diferenças na linha (ano).

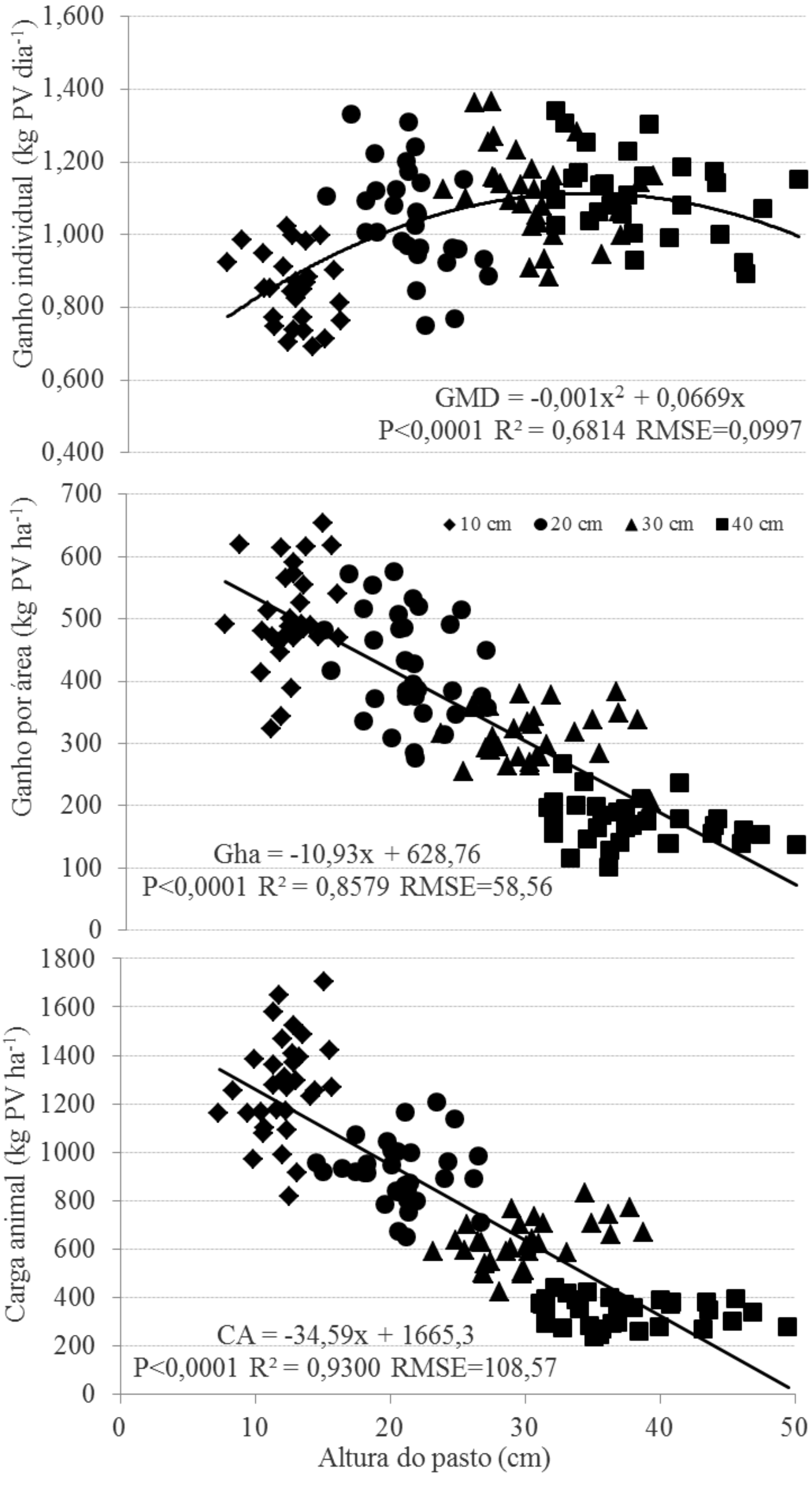

Figura 5. Ganho individual diário, ganho por área e carga animal de bovinos em função das alturas reais de manejo de pastos mistos de aveia + azevém ao longo de 10 anos de experimento sob sistema integrado de produção agropecuária.

3. CAPÍTULO III

How much do sod-based rotations reduce nitrate leaching in a cereal cropping system?[2,3]

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[2] Artigo redigido sob as normas da Revista Agricultural Water Managenement (Apêndice 2).
[3] Dados pertencentes à SOERE-ACBB.

How much do sod-based rotations reduce nitrate leaching in a cereal cropping system?

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Abstract - Nitrogen is essential for the improvement of agricultural production systems, and also why the contamination of groundwater by this nutrient is common. The aim of this paper is to provide data over 9 years for estimating leaching by using a simple computation procedure and measurements of soil humidity and water balance, nitrate concentration in drainage water and meteorological data and to assess the impact of the duration of the grassland phase and of the level of nitrogen fertilization on grassland on the drainage water quality. The study was conducted at the site Systems of Observation and Experimentation in Environmental Research- Agro-ecosystem, Biogeochemical Cycles and Biodiversity in Lusignan. The experimental treatments are sequences of maize, wheat and barley with different grassland rotational periods (a pure arable crop rotation; three or six years of grassland receiving a high nitrogen application; six years of grassland with a low N application rate and long term grassland with nitrogen application). The experimental period of this study lasted from April 2005 through June 2012. In all 9 years a large part of the drainage occurred in autumn and early winter. Treatments with the longest duration of grassland exhibited a lower drainage than treatments having a greater proportion of arable crops. In average nitrate concentration was 52.7 ± 38.63 $mgNO_3L^{-1}$ under pure crop rotation treatment as compared to 14.9 ± 14.76 NO_3L^{-1} under permanent grassland treatment. There were significant differences ($P < 0.0001$) in cumulative nitrogen leaching between the different cropping systems, between 9 and 37 $kgNha^{-1}year^{-1}$. Introduction of mowed grassland sequences with this arable crop rotation leads to a strong reduction of the nitrate concentration of the ground water, the more proportion of grassland within the rotation the more NO_3^- concentration is reduced, whatever the level of N fertilization during the grassland sequence.

1. Introduction

Nitrogen is central to the current agriculture production systems. On historic time scale improving nitrogen availability has been the main driver of improvement of crop yield (Sinclair and Rufy, 2012), and data aggregated at worldwide level and on several decades show a strong link between agriculture production and fertilizer use (Tilman et al., 2002). Nevertheless, the use of large amount of N in intensive agricultural systems has led, through nitrogen cascades (Galloway and Cowling, 2002), to important environmental contaminations (Robertson and Vitousek, 2009; Datta et al., 1997; Guillemin and Roux, 1992; Addiscott et al., 1991). Nitrate contamination of surface water and groundwater is common in watersheds dominated by agricultural activities (Jégo et al., 2012; Townsend et al., 2003). Nitrate leaching is a serious issue in a large area of cultivated land. The European Union has implemented a procedure aiming at recovering a good quality of water resources in 2015 (Directive 2000/60/EC) and Nitrate Directive (91/676/EC) has implemented is a law which aims to control nitrogen pollution limiting the nitrate concentration <50 mg/L in water. Land use is a key factor of nitrate pollution (Kopácek et al., 2013a; Kvítek et al., 2009). Indeed, several studies show that leaching is reduced in grasslands (Kopácek et al., 2013a; Kvítek et al., 2009). The reason for that is due to the strong coupling between C and N cycles associated with plant autotrophy and intense microbial biomass turnover under permanent vegetation (Soussana and Lemaire, 2014). Then even with large N fertilization rates nitrate leaching under grasslands managed by cutting remains very limited while under grazing N leaching is more directly related to stocking density whatever the origin of N inputs, N mineral fertilization or N_2 fixation (Ledgard et al., 2009). So introduction of grasslands into arable cropping systems as sod-based rotations or ley farming within integrated crop-livestock systems could be considered as an option for reducing local emissions of N into hydrosystems (Lemaire et al., 2014; Franzluebbers, 2007; Attard et al. 2011). However, several questions have to be answered concerning the environmental benefit of these systems: (i) the quantification of the grassland effect on drainage water quality at the level of a whole crop rotation according to the duration of the “grassland” phase and then on the relative importance of grassland area vs arable cropping area in the land use system; (ii) the impact of the level of intensification and more precisely of the N fertilization use during the grassland phase; and (iii) the analysis of the risk for peak of nitrate leaching after grassland re-cultivation as a consequence of a higher N mineralization associated to an increased soil organic matter (Bot and Benites, 2005), especially in cases where cereals are cropped with tillage.

Long term experiments are therefore required to assess the amount of nitrogen that is leached under different systems under the same soil and climate conditions (Kopácek et al., 2013b). The aim of this paper is to provide data over 9 years for estimating leaching by using a simple computation procedure and measurements of soil humidity and water balance, nitrate concentration in drainage water and meteorological data and to assess the impact of the duration of the grassland phase and of the level of nitrogen fertilization on grassland on the drainage water quality.

2. Material and methods

2.1 Study site and experimental design

The INRA Lusignan site (46°25'12.91N";0°07"29.35"E) as part of the SOERE ACBB (Systems of Observation and Experimentation in Environmental Research-Agro-ecosystem, Biogeochemical Cycles and Biodiversity http://www.soere-acbb.com/) is a long-term field experiment initiated in 2004. The Lusignan site has been designed by INRA to increase our understanding of the effects of temporary grassland management on the environmental outputs of mixing arable cropping/grasslands systems.

The experimental treatments are sequences of maize, wheat and barley with different grassland rotational periods (Figure 1). The treatment 1 (C) is a pure arable crop rotation of maize/wheat/barley and N fertilization rates adjusted for the potential yield achievable for each of these crops on this region. The treatments 2 (C3G3) and 3 (G6C3) are rotations of maize/wheat/barley alternating with three or six years of grassland receiving a high nitrogen application adjusted to achieve near maximum forage production. The treatment 4 ($G6C3N^-$) is similar to treatments 3 but with a low N application rate during the grassland phase. Treatment 5 (G) is a long term grassland with nitrogen application as for treatments 2 and 3. Grassland is composed of a mixture of *Festuca arundinacea* (*Cv* Soni), *Lolium perenne* (*Cv* Milca) and *Dactylis glomerata* (*Cv* Ludac). Management of the crop sequence was performed according agricultural practices to achieve a yield close to the potential determined in the region by soil and climate. N fertilization application rate and timing for all crop sequences were adjusted every year by using the software PC-AZOTE. For grasslands sequence regular estimations of the Nitrogen Nutrition Index (NNI) were performed according to the method described by Farruggia et al (2004). The timing and rate of fertilizer applications were regulated for maintaining NNI between 0.9 and 1.0, which i.e. close to a non-limiting N nutrition allowing for potential herbage production (Lemaire et al., 2008).

The experimental period of this study lasted from April 2005 through June 2012. The varieties seeded as well as the planting and harvesting dates and applications of nitrogen are shown in Table A1 (Appendix A). The five treatments were designed on a four block experimental system with individual plots of 4000 m^2 each.

2.2 Soil and meteorological data.

The soil is a Cambisol with silty-loamy texture in the surface and clay in the subsoil horizons (Chabbi et al., 2009). The percentage of clay at the study site ranged from 17% in the topsoil to 48% in depth soil horizon (Moni et al. 2010). The soil structural organization presented a large spatial variability and the distribution of vertical tongues characterizing the soil varied greatly amongst profiles (Chabbi et al. 2009; Moni et al. 2010).

Clay, silt and sand of 20 soil profiles data set were used for determination of field capacity (H_{fc}) for each soil horizon (Angevin, 1999) according to equation from Campbell using the software SoilPar 2.00 (Acutis and Datelli, 2003) after comparison with other approaches and measured humidity in the field (data not shown).

Volumetric soil humidity was measured with TDR sensors for each treatment only on blocks 1 and 2. The measures were made every 30 minutes. There were 8 sensors in each replicate plot, one sensor at -10, -20, -30 and -80 cm and two sensors at -60 and -100 cm. Minimum humidity (H_{min}) registered during the period of each crop was used for the calculation of soil maximum soil available water, designated as water reserve in the following.

The local daily data of rainfall (Figure 2), maximum and minimum air temperatures and relative humidity at 2 m height, irradiance and wind speed (2m) were measured on the site of the experiment and obtained from the Climatik database maintained by AgroClim INRA.

2.3 Water collects and nitrate concentrations

In order to measure the nitrate concentration of the drained waters, gravitational soil solutions were collected by using zero-tension plate lysimeters (ZTL) according to methodology described in Ranger et al (2001). Two ZTL were inserted in soil at -105 cm depth in each plot of blocs 1 and 2 before the start of the experiment in 2004. Water drained from each plate in each period was cumulated in collecting glass bottles located in pits built near the plots and under the plate level. Samples were taken during each drainage event lasting less than 15 days or every 15 days during drain periods longer than 15 days. A 500 mL Aliquots of the weekly-pooled material were then analyzed for nitrate N concentrations (NO_3^-N) by ion chromatography at the certified IANESCO laboratory in Poitiers. Although the ZTL system did not allow any quantitative evaluation of the water drainage flow to be made, due to the error associated to such an open system it allowed a reliable sampling method for qualitative approach (Ranger et al., 2001). So for quantification of nitrate flow to groundwater table it is necessary to have an independent estimation of soil water balance and drainage.

2.4 Calculation of evapotranspiration, soil water reserve and drainage.

Evapotranspiration (ETR) was calculated as a function of reference evapotranspiration (ET^0) multiplied by crop coefficients (K_c). The ET^0 was calculated as a function of global radiation, temperature, humidity and wind speed. These values are routinely computed and downloaded from the Climatik data base. Crop coefficients were found in the FAO document for wheat, maize, barley and grassland for each stage of crop development (Allen et al., 2006). The actual evapotranspiration was further reduced depending on the relative soil water content.

To take the impact of the soil water content on ETR into account, the soil was divided into three layers (Figure 3): one surface layer 0-20 cm; one layer explored by roots (for each crop) which increased in depth from 0 at sowing to a maximum depth at flowering; and a deep layer which was the maximum depth reached by roots during the whole period studied (2006-2013). The maximum depth was estimated using the humidity profiles measured throughout the experiment.

K_c was actualized every day following the crop development, and assuming it was 0.3 at sowing and maximum at flowering. Flowering date was derived from the value growing degree days provided for maize, wheat or barley (Table A1 – Appendix A). In each case, the maximum value of K_c was taken from the FAO (Allen et al., 2006). The root depth was proportional to Kc, growing from zero at sowing to maximum root depth on day of flowering. The maximum root depth was computed for each crop and plot using the profile of minimum soil water content observed over 100 cm, extrapolating the depth value at which soil humidity would be equal to field capacity (eg, Figure 4). Further details of the computation of ETR and drainage, depending on development stage of the crops, are given in appendix B.

2.5 Statistical methods.

Data were subjected to analysis of variance and contrasts with significance level of 5%. Drainage data were also analyzed for each period (crop). For these analyzes, the GLM and Mixed of SAS software (SAS, 2002) package was used.

3. Results.

3.1 Estimate of drainage

Maximum soil water reserve (Table 1) was similar between treatments (P= 0.0957), allowing the evaluation of treatment effects on water draining from the soil and leaching of nitrogen.

The dryness of soil profiles varied between years and treatment. The driest year (intensity and duration) was 2006 followed by 2009. The soil relative water content remained relatively high during the other years, 2007 and 2013 exhibiting the wettest conditions (Figure 5). As expected, with grassland, soil dried out more rapidly and to drier situations than with crops. However, the deepest root activity measured, approximately 155 cm, was observed under continuous cropping with cereals.

Figure 6 shows a good correspondence between the determination of the drainage events observed directly on ZTL and the period of drainage calculated through the model that demonstrates the reliability of measurement methodology for sampling gravitational soil water contributing to drainage. In all 9 years a large part of the drainage occurred in autumn and early winter (Figure 6). However, we also observed drainage during the period of spring 2013 due to the large rainfall (Figure 2). The cumulative drainage during the 9 years (Figure 7) was different among cropping systems ($P < 0.0001$). Treatments with the longest duration of grassland (G and G6C3) exhibited a lower drainage than treatments having a greater proportion of arable crops: 1991 and 1943 mm, respectively for G and G6C3 against 2658 and 2357 mm respectively for C and C3G3, while G6C3N$^-$ remained intermediary (2147mm). The two periods during which the largest difference between treatments occurred were the winter 2007-2008, and 2010-2011, *i.e.* under the long bare soil between the barley harvest in early summer and maize sowing in next spring.

3.2 Nitrate concentration of gravitational soil water

A large variation with time can be observed in the nitrate concentration of gravitational soil water collected from ZTL (Figure 6) for all drainage periods under grassland (G) or under pure arable crop system (C), in each situation. Under pure crop rotation nitrate concentration varied from 5 up to 145 mg NO_3L^{-1} while under grassland this variation is of less amplitude, from 0 up to 64 mg NO_3L^{-1}. In average nitrate concentration was 52.7 ± 38.63 mgNO_3L^{-1} under C treatment as compared to 14.9 ± 14.76 NO_3L^{-1} under G treatment. As expected land occupation with grassland managed by cutting lead to an important reduction of nitrate concentration of drained water as compared with pure arable crop rotation. On average treatments with a high proportion of grassland (G, G6C3, G6C3N-) provide water with approximately 15 mg NO_3L^{-1} in comparison to the pure crop rotation (C): 53 mgNO_3L^{-1} while the treatment C3G3 gave intermediary result 31 mg NO_3L^{-1} (P = 0,0003).

Although this comparison obtained through the average of gravitational water sampling is only an approximation of the overall nitrate concentration of drained water. A more relevant estimate of the quality of drained water needed to weigh each sampling value by its contribution to the volume of drained water. This was assessed using the drainage on the one hand and the total nitrate lixiviated over a period on the other hand.

3.3 Nitrate lixiviation

For each drainage period, the nitrate concentration of water sample was multiplied by the quantity of water drained for calculating a quantity of nitrate leached. The cumulated quantities during the 9 years of the experiments are represented in Figure 8. There were significant differences (P <0.0001) in cumulative nitrogen leaching between the different cropping systems (Figure 8). In the pure arable crop system (C) 340 kg N ha^{-1} leached over the 9 years, *i.e.* a loss of 37 kgN$ha^{-1}year^{-1}$ while under long term grassland (G) and systems including period of 6 years of grassland, (G6C3 and G6C3N^-), an average of only 70 kgNha^{-1} over the 9 years was recorded, *i.e.* a loss of 8 kgNha^{-1}. Over the whole 9 year studied, lowering N fertilization did not result in any further significant decrease in N leaching. The C3G3 system showed an intermediate value of 165 kg Nha^{-1}, corresponding to a loss of 18 kgN$ha^{-1}year^{-1}$.

A more detailed analysis was made for the period following the 6 year or 3 year grassland, *i.e.*, April 2011 – July 2013 when a common arable crop sequence started following 6 years of different land occupation (Table 2). For all treatments N leaching occurred in two steps: Winter-Spring 2012 and Winter-Spring 2013. No additional N leaching due to the grassland ploughing and re-cultivation was detected during these two periods for C3G3 or G6C3. Although limited, the effect of N fertilizer application on grassland N leaching after its re-cultivation was significant (34 *vs* 17 kgNha^{-1} for G6C3 and G6C3N^- respectively following the wheat crop) and did not persist thereafter. Under continuous grassland treatment (G), N leaching was relatively important during the second period as compared with the very low N leaching during the previous years. This could be associated with the intense drought in summer and autumn 2012 (Figure 5).

The overall nitrate concentration of drainage water can then be calculated for each treatment as the ratio between the cumulated loss of nitrogen per hectare (Figure 8) and the cumulated volume of drainage water (Figure 7) that should give the best estimate of the contribution of each treatment to the water quality of the ground water. The ratio of cumulated NO_3 leached over the quantity of water drained during the whole period showed that the water from the crop rotation had a concentration of approximately 56 mg NO_3L^{-1}, while treatments with continuous or 9, 6 or 3 year grasslands had 14, 19 and 31 mg NO_3L^{-1}, respectively (Figure 8). The 6 year grassland rotation with low N application (G6C3N-) had the same average concentration as the continuous grassland with high N application (G): 12 mg NO_3L^{-1}.

4. Discussion.

4.1 Effect of land use and management system on drainage

In the present study the drainage periods were usually observed between October and April since the evaporative demand in summer is generally sufficient to restrict drainage to infrequent events of very intense rainfall at this time of year (Cuttle and Scholefield, 1995). So drainage under land use systems favoring periods of bare soil is higher because of a lower evapotranspiration than under permanent vegetation. The difference in drainage between land use systems differing in the proportion of grassland occurs more specifically during these period of bare soil (Figure 6 and Table 2). In consequence, introduction of grassland within cereal rotation leads to a reduction of the quantity of leaching water. To quantify the current rate of aquifer recharge is thus a prerequisite for efficient and sustainable groundwater resource management in dry areas, where such resources are often the key to economic development (Vries and Simmers, 2002). The balance between land areas covered by grasslands and cropping areas at catchment level should be obtained for sustainable water resource management.

4.2 Effect of land use on nitrate leaching and gravitational water quality

Leaching of nitrates into groundwater and their presence in surface runoff depends on mineral nitrogen excess, hydrological regime, land use, soil type and climatic conditions (Shepherd et al., 2001; Oenema et al., 2005). Several studies pointed out the relationship between land use and leaching of nitrogen (Kvitek et al., 2009). Nitrate concentrations in drainage from grassland or forest are usually small (Addiscot, 2005). For the same author, systems with rotating annual crops leave the soil bare for part of the year, and while the soil is bare, soil nitrogen is vulnerable to leaching because there are no live plants to capture it. Also important is the fact that the grasses spread their roots in soil depths enabling the plants to capture nitrate before it can leach and contaminate water or be leached (Franzluebbers et al., 2014). Moreover, the permanency of carbon flow through perennial vegetation to soil under grassland allows a rapid N immobilization-mineralization turnover by soil microbes that avoid the accumulation of N as nitrate in soil and then reduce the risk of leaching (Premrov et al., 2012; Tlustos et al. 1998).

The first events of each period of drainage are those with the highest levels of nitrogen concentration in gravitational water (Figure 6). At the end of summer high soil temperatures and the restoration of soil humidity, N mineralization is favored, leading to accumulation of mineral N in soil and increasing concentration of nitrate within gravitational water (Engström et al., 2011; Torstensson and Aronsson, 2000; Stenberg et al., 1999). According to the model of Burns (1974) the nitrate concentration of drainage water is high at the start of the drainage period near the end of autumn and due to the leaching effect tends to decrease as the volume of water drained increases. So, as the volume of drainage water increases bringing about a dilution process, according to this model, the average NO_3^- concentration of drainage water should decrease. As a consequence, any reduction in the volume of water drainage should automatically increase the average NO_3^- concentration of the water drainage. But analysis of the relationship between volume of water drainage and corresponding average NO_3^- concentration show a positive correlation across treatments or across years ($r=0.93$ $P<0.0001$) that is in contradiction with what it was expected from the model of Burns. In fact for each drainage period as it was expected a tendency to a “dilution” of nitrate concentration as the volume of water drainage increase was observed as expected. But because the soil N mineralization remains active through all the winter and increases in early spring this “dilution” process is largely attenuated or erased when analyzed at a whole year level. Therefore any reduction of the drainage water volume, due to either a reduction of the annual rainfall or an increase of evapotranspiration through a better soil cover by vegetation would have contributed to an increase in the average nitrate concentration of drainage water. So the high capacity of grasslands to intrinsically decrease the accumulation of nitrate in soil is not impaired by its higher capacity to reduce the volume of water through a lower “dilution” effect.

Even with higher N fertilization application rates than in maize, wheat and barley (Table A1 – Appendix A) grassland always shows both a lower quantity of nitrate leaching and a lower nitrate concentration of drainage water. This can be explained by the absence of soil disturbance and of the periods of bare soil during the “grassland phase”. In arable cropping systems, large amounts of nitrogen that remain in soil or are mineralized after harvest may be leached before the next crop is established (Sapkota et al, 2012). It is interesting to note here that the high increase in fertilizer N application rate on grassland in G6C3 treatment as compared to G6C3N$^-$ treatment did not lead to any substantial increase in nitrate leaching risk. That underlined the high capacity of mown grasslands for restoration of ground water quality even under a relatively intensive management system allowing the near potential herbage production (Table A1 – Appendix A). So as shown in Figure 9, an increasing proportion of grassland within cereal rotations would lead to a strong exhaustion of the nitrate concentration of drainage water according to an exponential function.

4.3 Effect of grassland destruction and re-cultivation.

Some authors have stressed that the advantage of introduction of temporary grasslands within arable cropping rotations for reducing the nitrate concentration of groundwater could be lost during the 2 year periods following the conversion of land from grassland to annual crops (Kaspar et al., 2012; Vertès et al., 2007; Cuttle and Scholefield, 1995), because the high mineralization rate of the soil organic matter incorporated in soil after grassland destruction and re-cultivation. In our situation we did not observed any lasting effect of the preceding land use system (continuous arable cropping, alternation 3 years crops and 3 years grassland, or 6 years grassland with high or low N fertilization) during the 3 subsequent years of maize, wheat, and barley rotation. As shown in Table 2, the maize crop sown in April 2011 just after the grassland destruction and receiving a relatively low N fertilization rate according to indication of the PC-AZOTE software (Angevin, 1999) avoided nitrate leaching until

November 2011. Only two periods of N leaching were observed under wheat (2012) and Barley (2013) and the quantity of nitrate losses by leaching after grassland never excess the quantity lost under continuous cropping system. This absence of excess of N leaching after grassland conversion into arable crop has been obtained through a moderate N fertilizer rate on maize allowing this crop to uptake most of the supplemental N mineralized after grassland ploughing. The agronomic analysis of N balance across treatments is not the objective of this paper, but it is interesting to note that variations in maize grain yield across treatments (Table A1: 7.6; 7.7; 8.4; and 7.0 tha^{-1} respectively for C, C3G3, G6C3 and G6C3N^{-}) reflects probably only small differences in plant N nutrition. So if the grassland destruction is followed immediately by a crop with a high N uptake capacity as maize with a moderate N fertilization application rate then the risk for supplement N leaching risk should be low. It was interesting to note that in this experiment grasslands were only used under mowing, while most of the work that indicated increased risk of nitrate leaching after grassland destruction was carried out under grazing management.

4.4 System comparison

The experimental design used was an attempt for analyzing the effect of some forcing variables such as land use system (crop *vs* grassland), level of N fertilization application on grassland on the quantity and quality of drainage water. This system allows the answer to question such as “*What if..?*”, but it cannot answer to “*What is necessary for…?*”. In other terms it allows the analysis of the consequence of some agriculture system decisions, but it cannot directly help in providing the best management decision for a given set of production and/or environment objectives in a particular situation. It is clear that the pure cropping system could have been managed with the introduction of catch crops during the periods of bare soils. It has been demonstrated that catch crop incorporation should reduce a part of the risk of nitrate leaching under arable cropping system (Kaspar et al., 2012; Vertès et al., 2007; Cuttle and Scholefield, 1995). But incorporation of a supplemental treatment within a long term experiment using intensive measurements of different variables is not so easy, and the best solution is to limit the number of land use and management system for calibrating models and then to use models for investigating other variations and combinations of management systems. Furthermore, as maize is harvested in late October or even later in some region, and given the short period of time available for sowing and crop setting it is very difficult to expect any significant nitrate uptake during winter using catch crops. In this cereal system the use of catch crops would be only possible between the harvest of barley in July and the sowing of maize on April of the following year that represents the period of the highest risk for Nitrate leaching. Ter Steege et al. (2001) showed that, based on experimental data and modeling simulation, introduction of catch crops within annual cropping systems could remove until 50% of the nitrate leaching that corresponds to the abatement obtained with the treatment C3G3.

These first analyses of the experimental data of the SOERE-ACBB of INRA-Lusignan over the first 9 years allows the drawing of first conclusions:

(i) In the soil and climate condition of Central West France the use of a pure cereal cropping system managed with just enough N fertilization as require for regional potential grain yield achievement leads to an average nitrate concentration of the drainage water higher than the limit of 50 $mgNO_3^-L^{-1}$ admissible for drinking water.

(ii) Introduction of mowed grassland sequences with this arable crop rotation leads to a strong reduction of the nitrate concentration of the ground water, the more proportion of grassland within the rotation the more NO_3^- concentration is reduced, whatever the level of N fertilization during the grassland sequence.

(iii) Destruction of grasslands by ploughing and re-cultivation did not lead to over N leaching, so the advantage gained during the grassland phase on water quality is conserved over the whole sod-based rotation.

(iv) Nevertheless in regions where water availability strongly depends on recharge of aquifers in winter, a trade-off between the advantage of grassland introduction within arable cropping system in terms of ground water quality and the possible disadvantage linked to a reduction of the volume of drainage water. Such a trade-off should be given attention for catchment management.

Several questions remains open for future analysis, by using either other measurements made as co-variables on water quality (pesticides, phosphate, sulfate and cations) or by using model simulations for testing different crop system scenarios such as use of catch crops, tillage *vs* non-tillage and cutting-grazing equilibrium.

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6. Appendix

6.1 Appendix A.

6.2 Appendix B.

The soil is split in three layers: the 20 top cm, the layer explored by the current crop's roots and the deepest root layer over the whole 8 year period studied. When the soil was bare the top 20 layer contribution to ETR of the day j (ETR_{20}^{j}) was computed using equation (B.1):

$$ETR_{20}^{j} = K_{20} * ET° * Min\left(1; \frac{R_{20}^{j}}{0.4RU_{20}}\right) \tag{B.1}$$

Where, K_{20} was set constant equal to 0.3 (Allen et al., 2006), R_{20}^{j} is the daily soil water reserve of the 20 cm layer of the day j and RU_{20} is the maximum available water of the 20 cm layer. R_{20}^{j} and RU_{20} were determined using equations (B.2) and (B.3):

$$R_{20}^{j} = Min\left(RU_{20}; R_{20}^{j-1} + P^{j} - ETR_{20}^{j}\right) \tag{B.2}$$

$$RU_{20} = \{[(H_{10}^{fc} - H_{10}^{Min}) * 10] + [(H_{10}^{fc} - H_{20}^{Min}) * 10 + (H_{20}^{Min} - H_{10}^{Min}) * 5 + (H_{20}^{fc} - H_{10}^{fc}) * 5]\} \tag{B.3}$$

Where R_{20}^{j-1} is the available water of the top layer of the day j-1, P^{j} is the rainfalls of the day j, H^{Min} is the minimum humidity and H^{fc} is the field capacity humidity in each depth. H^{fc} was calculated using the software Soilpar 2.00 (Acutis & Donatelli, 2003).

When Root depth was deeper than 20cm, ETR was computed using equation (B.4).

$$ETR^{j} = \left[K_{c} * ET^{\circ} * Min\left(1; \frac{R_{R}^{j-1}}{0.4RU_{R}} \right) - ETR_{20}^{j} \right] \tag{B.4}$$

Where R_{R}^{j} and RU_R are the soil available water content of the day j-1 and the maximum available water content in the root zone below 20 cm, respectively. R_{R}^{j} was determined using equation. (B.5)

Drainage between top layer and root zone and under the root zone was computed making the balance on each layer and neglecting the capillary rise because the water table is 30 m under the ground, approximately (equations B.5, B.7 and B.9).

$$R_{R}^{j} = Min\left(RU_{R}; R_{R}^{j-1} - (ETR^{j} - ETR_{20}^{j}) + D_{20}^{j-1} \right) \tag{B.5}$$

Where D_R^{j-1} is the drainage under the root zone and was determined using equation (B.6).

$$D_{20}^{j-1} = \left(RU_{20} - (R_{20}^{j-1} + P^{j} - ETR_{20}^{j}) \right) \tag{B.6}$$

$$R^{j} = Min\left(RU; R^{j-1} - (ETR^{j} - ETR_{20}^{j}) + D_{R}^{j-1} \right) \tag{B.7}$$

$$D_{R}^{j-1} = \left(RU_{R} - (R_{R}^{j-1} + P^{j} - ETR^{j}) \right) \tag{B.8}$$

$$RU_{R} = \Big\{ \left[\left(H_{10}^{fc} - H_{10}^{Min} \right) * 10 \right] + \left[\left(H_{10}^{fc} - H_{20}^{Min} \right) * 10 + \left(H_{20}^{Min} - H_{10}^{Min} \right) * 5 + \left(H_{20}^{fc} - H_{10}^{fc} \right) * 5 \right] + \left[\left(H_{20}^{fc} - H_{30}^{Min} \right) * 10 + \left(H_{30}^{Min} - H_{20}^{Min} \right) * 5 + \left(H_{30}^{fc} - H_{20}^{fc} \right) * 5 \right] + \left[\left(H_{30}^{fc} - H_{60}^{Min} \right) * 30 + \left(H_{60}^{Min} - H_{30}^{Min} \right) * 15 + \left(H_{60}^{fc} - H_{30}^{fc} \right) * 15 \right] + \left[\left(H_{60}^{fc} - H_{80}^{Min} \right) * 20 + \left(H_{80}^{Min} - H_{60}^{Min} \right) * 10 + \left(H_{80}^{fc} - H_{60}^{fc} \right) * 10 \right] + \left[\left(H_{80}^{fc} - H_{100}^{Min} \right) * 20 + \left(H_{100}^{Min} - H_{80}^{Min} \right) * 10 + \left(H_{100}^{fc} - H_{80}^{fc} \right) * 10 \right] + \left[\left(H_{Max\ depth}^{fc} - H_{100}^{Min} \right) * \frac{(Max\ depth - 100)}{2} \right] \Big\} \tag{B.9}$$

Where *max depth* is the maximum root depth for each crop in each plot. For each plot, the values RU_{20}, maximum root depth and maximum RU are given in Table 1.

The drainage under the maximum root depth of the day j (D^j) is determined according to equation (B.10).

$$D^j = \left(RU \ - (R_R^{j-1} + P^j - ETR^j)\right) \tag{B.10}$$

Were RU is the maximum available water for 9 years.

For calculating the amount of nitrate leached, the Nitrate concentration (%Nitrate^j) of drained water was linearly interpolated between two samples values. Nitrogen leaching was calculated according to equation (B.11).

$$N_{leaching} = D^j * \%Nitrate^j * 0.226 \tag{B.11}$$

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Table 1. Soil water reserve in 20 cm depth and maximum and maximum depth roots

	Soil water reserve (mm)		**R_{max} depth**
	20 cm	**Maximum**	**(cm)**
C 1	34	155	155
C 2	38	163	143
C3G3 1	41	148	168
C3G3 2	48	179	139
G6C3 1	46	181	138
G6C3 2	51	194	143
G6C3N^- 1	43	153	125
G6C3N^- 2	39	148	130
G 1	42	168	137
G 2	41	171	136

Table 2. Nitrogen leaching and rainfall between treatments over the three years following the destruction and the ploughing of the grass

	Nitrogen leaching (kg N/ha)					Rainfall (mm)
	C	C3G3	G6C3	G6C3N$^-$	G	
Apr – Sep/11 (Maize)	5	0	0	0	0	280
Sep – Nov/11 (Bare soil)	0	0	0	0	0	68.5
Nov/11 – Jul/12 (Wheat)	39 a*	21 bc	34 ab	17 c	15 c	618
Jul – Nov/12 (Bare soil)	0	0	0	0	0	163.5
Nov/12 – Jul/13 (Barley)	22 a	33 a	36 a	34 a	26 a	893.5
Total leaching	66 a	54 ab	70 a	51 ab	41 b	2023.5

*Different letters mean differences between treatments in the period (P=0.0004) or total leaching (P=0.0096).

Figure 1. Sequence of soil occupation for the different treatments. The period between the end of each crop sequence (harvest) and the beginning of the following crop (sowing) correspond to bare soil.

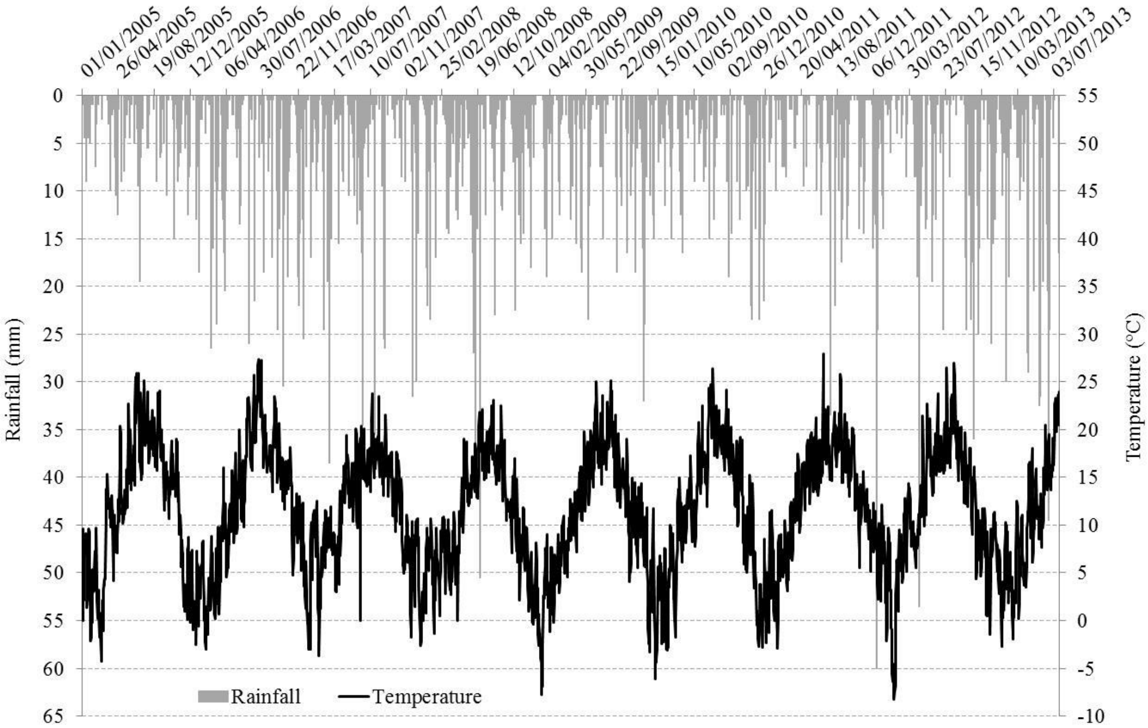

Figure 2. Rainfall and temperature measured on the site of the experiment.

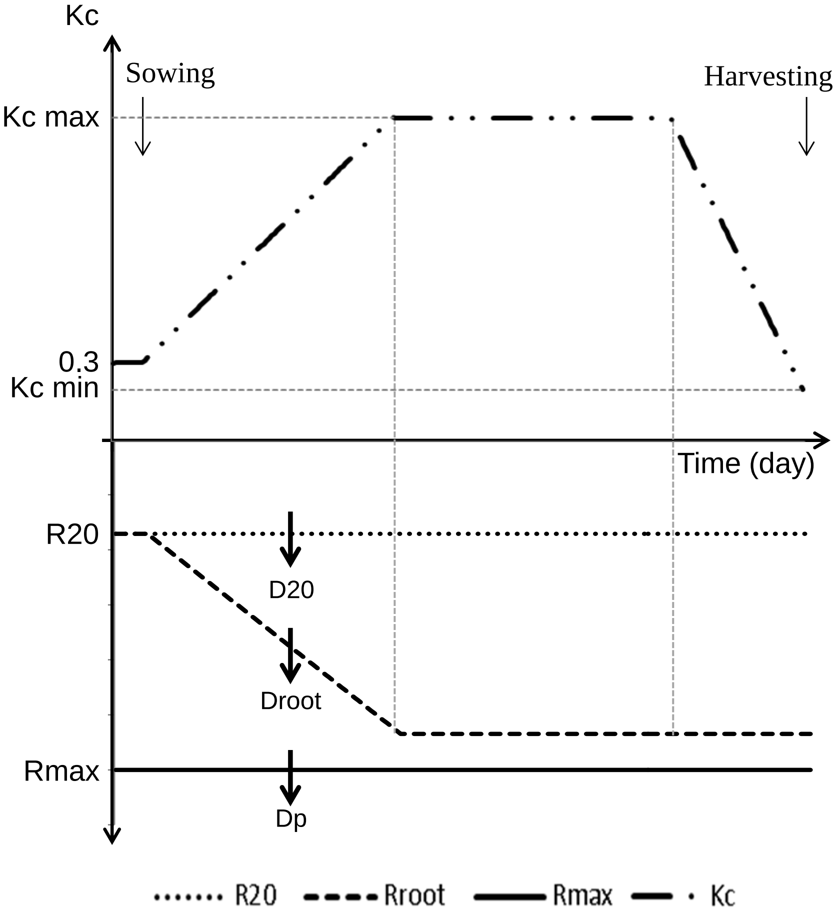

Figure 3. Evolution of the three soil water reserve modeled for the estimation of soil water and nitrogen leaching. The ground surface (R20) is divided into a tank of at least 20 cm deep, a reservoir between 20 cm and root depth (where they are deeper than 20 cm – Rroot) and a reservoir between the root depth and the maximum depth observed during the 9 years of the trial (Rmax). Root depth zero at the time of implantation, is proportional to the coefficient of the crop (K_c) and hence increases as a function of the sum of temperature. Water flows are expected only vertical and rising damp considered negligible in Lusignan. Drainage is calculated as the difference between the water balance of each tank and its useful reserve when higher.

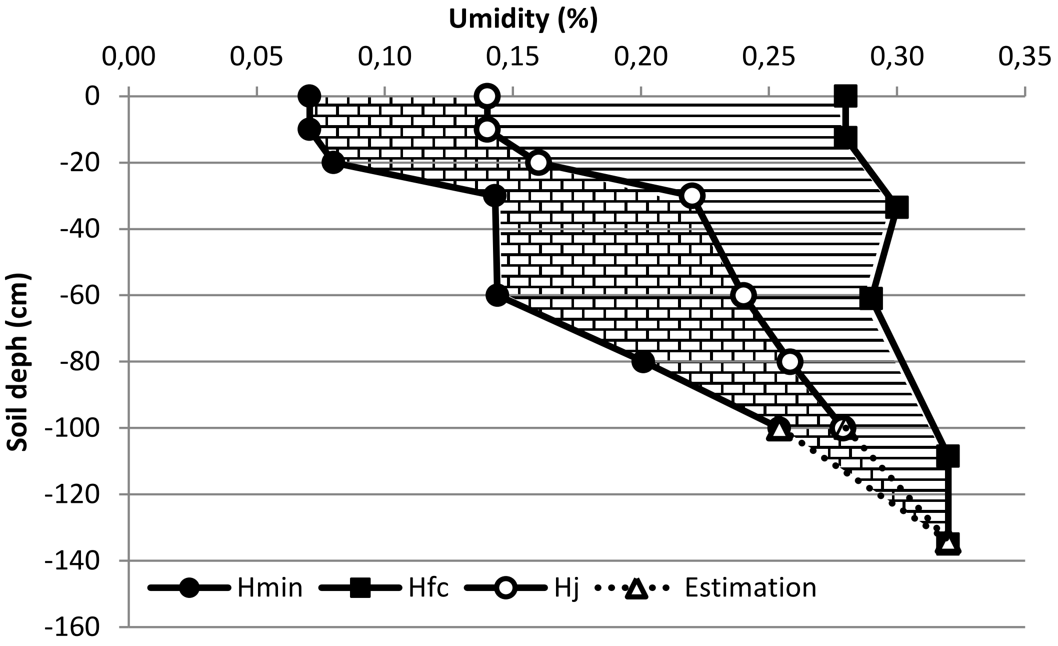

Figure 4. Illustration of the methodology for calculating the soil water reserve (Grassland in Oct/2010). Hmin is the minimum humidity, Hfc is the field capacity humidity in each depth and Hj is the day humidity.

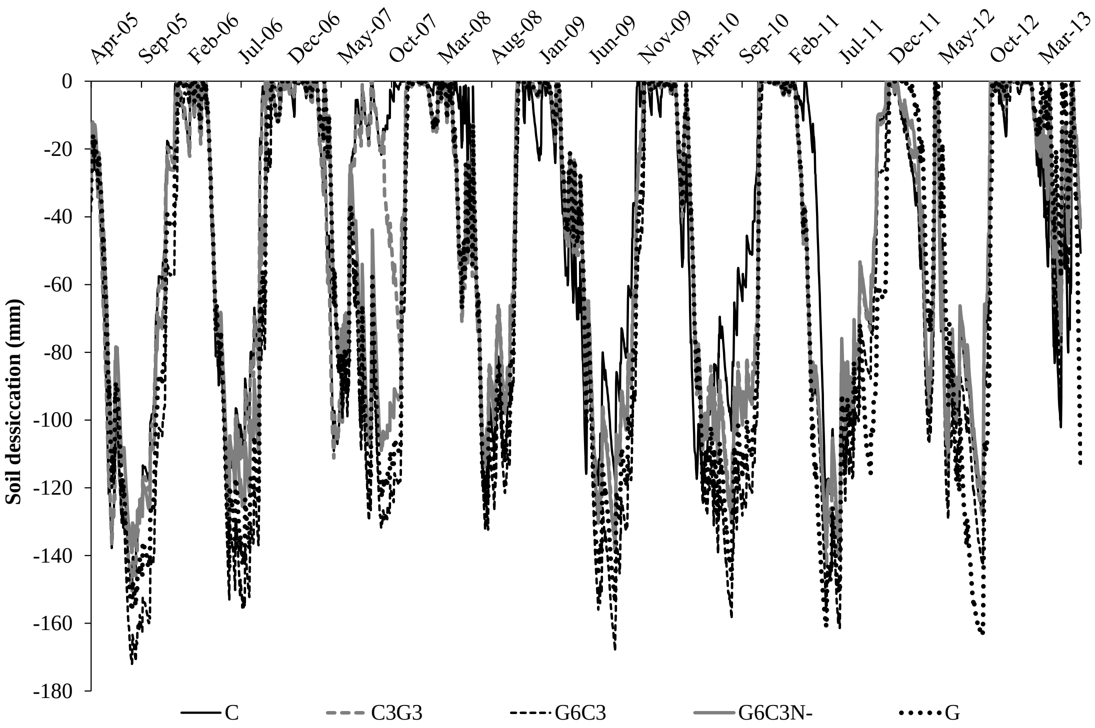

Figure 5. Comparison of soil water reserve evolution for the five treatments over the 9 years.

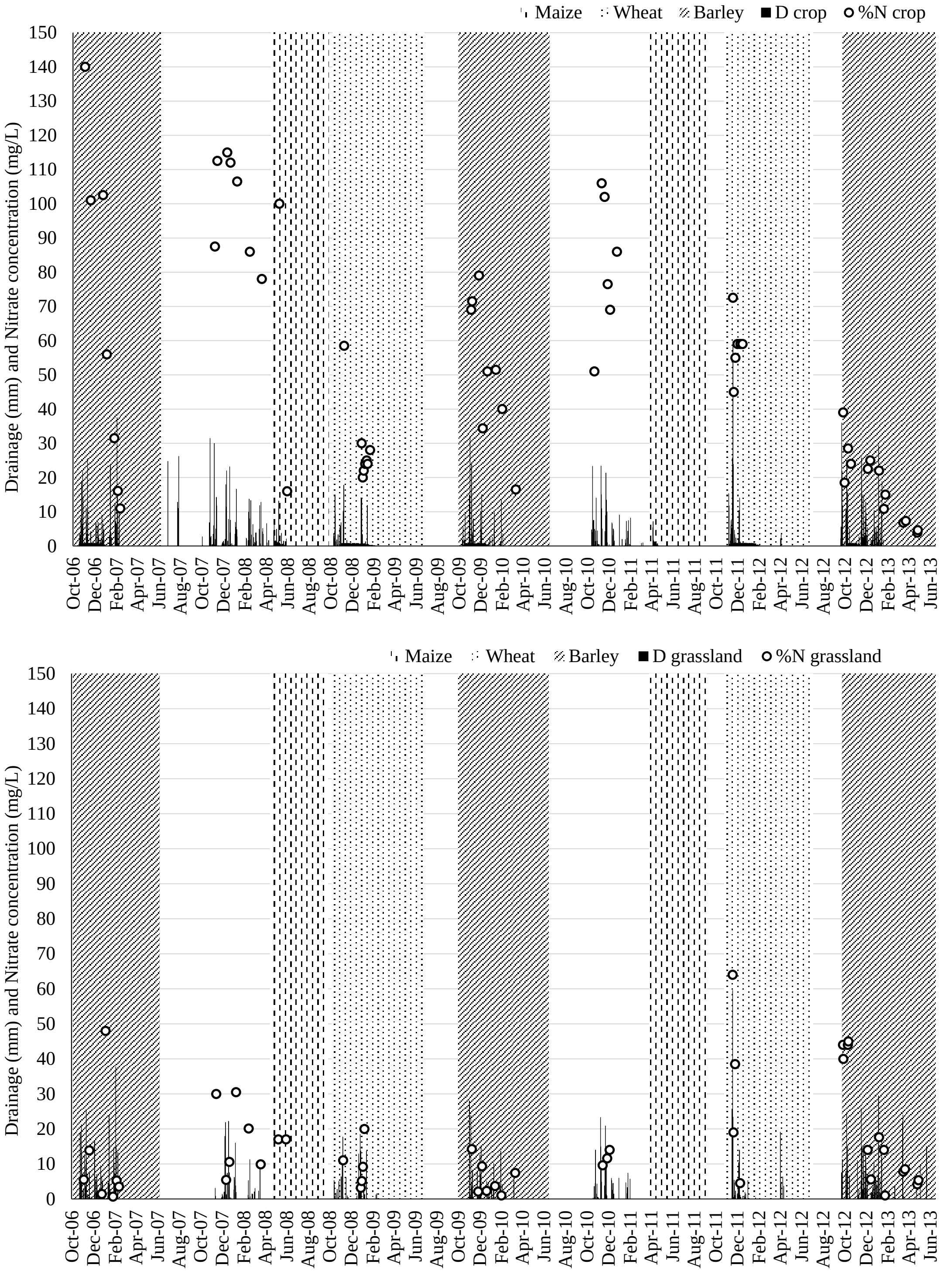

Figure 6. Estimated drainage and nitrate concentration of soil solution collected by lysimetric plates for treatment C (a) and G (b).

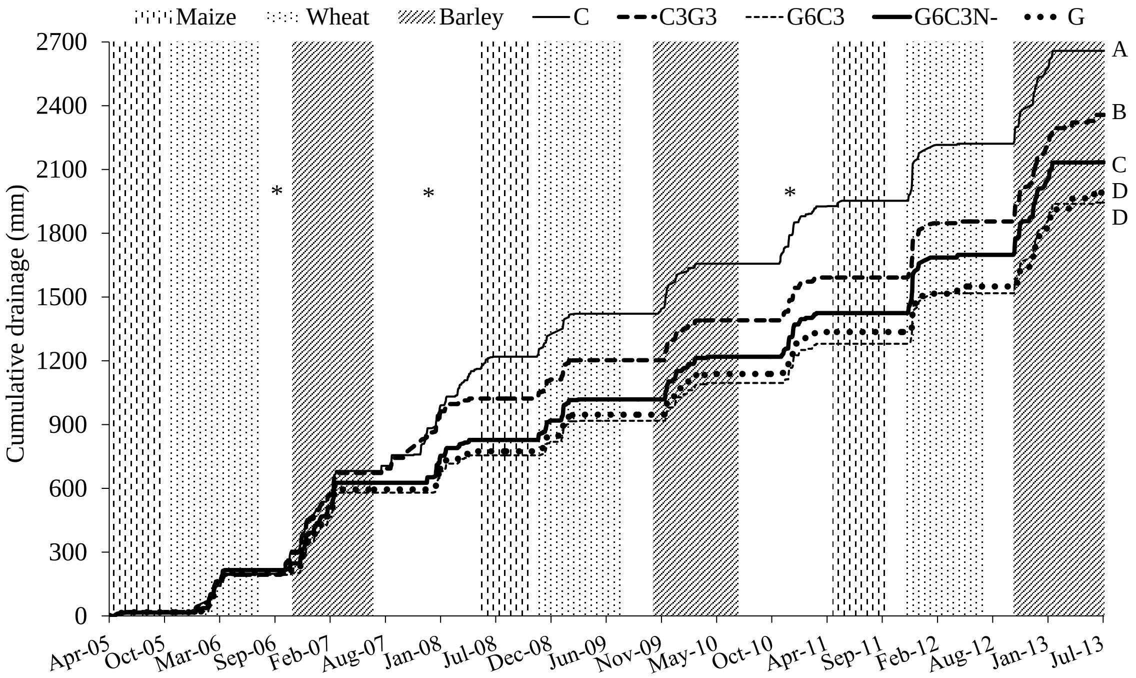

Figure 7. Comparison of the evolution of the cumulative drainage over the 9 years between the 5 treatments. (*significant difference between treatments in the periods; different letters mean differences between treatments for cumulative drainage; P>0.0001).

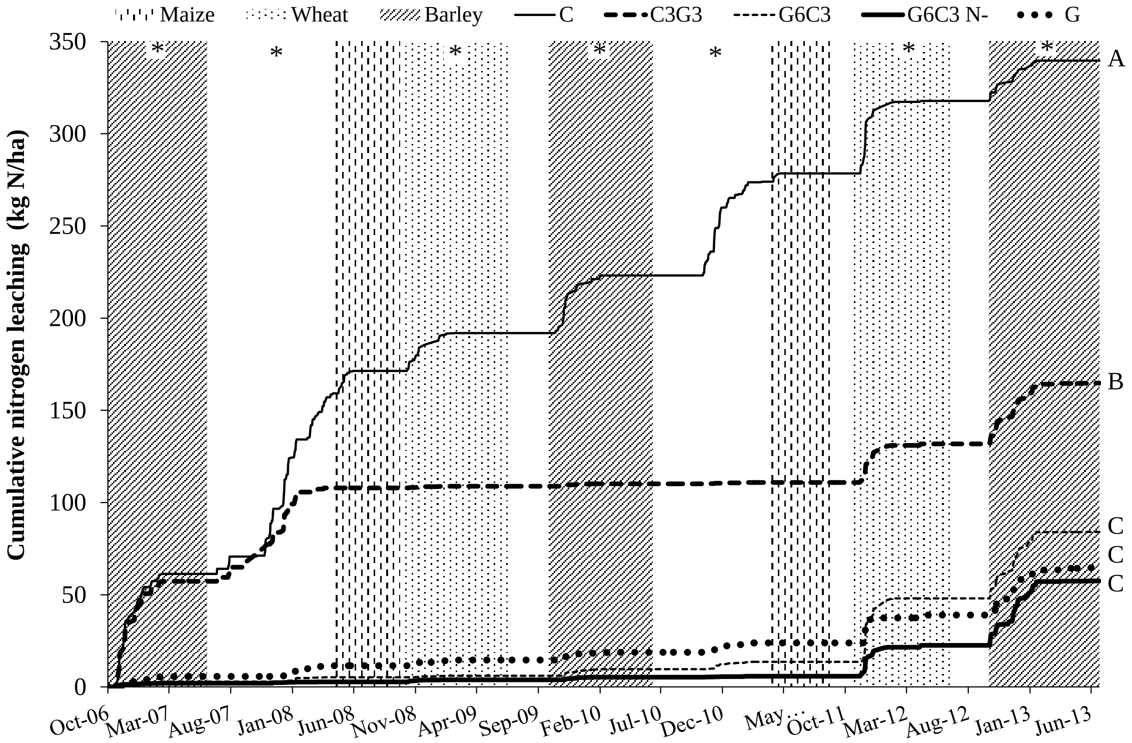

Figure 8. Comparison of the evolution of the cumulative nitrogen leaching between the 5 treatments over the 9 years. (*significant difference between treatments in the periods; different letters mean differences between treatments for cumulative nitrogen leaching; P>0.0001).

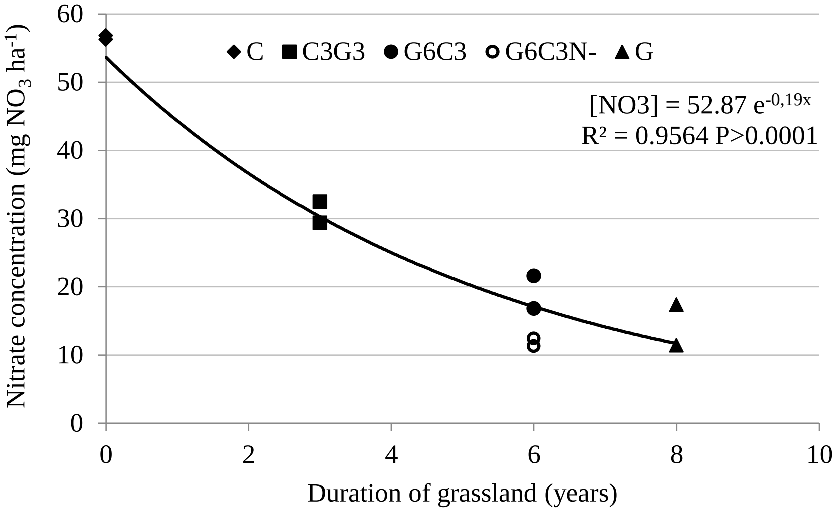

Figure 9. Average nitrate concentration of drained solution as a function of the duration of grassland in a mixed cropping system over 9 years.

Table A1. Varieties, sowing and harvesting dates of crops, crop coefficient maximum, total amount of nitrogen applied (kg N ha^{-1}) and crop yield (culture: kg grain ha^{-1} grassland: kg DM ha^{-1}) in the different treatments

	Year	Crop	Varieties	Sowing	Harvesting	K_c max	Nitrogen Applied	Yield (kg/ha)
C	**2005**	**Maize**	Texxud	21/04	22/09/2005	1.20	117	2524
	2006	**Wheat**	Caphorn	24/10/2005	19/07/2006	1.15	85	6864
	2007	**Barley**	Vanessa	26/10/2006	28/06/2007	1.15	120	4559
	2008	**Maize**	Anjou 387	07/05	17/10/2008	1.20	80	11638
	2009	**Wheat**	Caphorn	29/10/2008	16/07/2009	1.15	150	5898
	2010	**Barley**	Vanessa	22/10/2009	06/07/2010	1.15	83	4235
	2011	**Maize**	PR38V12 PIONER	18/04	27/09/2011	1.20	72	7644
	2012	**Wheat**	Caphorn	16/11/2011	24/07/2012	1,15	160	5627
	2013	**Barley**	Limpid	16/10/2012	16/07/2013	1,15	90	4638
C3G3	**2005**	**Maize**	Texxud	21/04/2005	22/09/2005	1.20	117	2577
	2006	**Wheat**	Caphorn	24/10/2005	19/07/2006	1.15	175	6825
	2007	**Barley**	Vanessa	26/10/2006	28/06/2007	1.15	120	4443
	2008	**Grassland**	Dactyle Ludac + Fétuque Soni + Ray-grass Milca	17/09/2007	-	1.00	330	14204
	2009						230	10563
	2010						210	5690
	2011	**Maize**	PR38V12 PIONER	18/04/2011	27/09/2011	1.20	36	7704
	2012	**Wheat**	Caphorn	16/11/2011	24/07/2012	1.15	160	5443
	2013	**Barley**	Limpid	16/10/2012	16/07/2013	1,15	90	4960
G6C3	**2005**	**Grassland**	Dactyle Ludac + Fétuque Soni + Ray-grass Milca	20/04/2005	-	1.00	0	0
	2006						170	10673
	2007						380	15873
	2008						330	12087

	2009						230	9592
	2010						210	5495
	2011	**Maize**	PR38V12 PIONER	18/04/2011	27/09/2011	1.20	36	8455
	2012	**Wheat**	Caphorn	16/11/2011	24/07/2012	1.15	160	5714
	2013	**Barley**	Limpid	16/10/2012	16/07/2013	1.15	90	5170
G6C3N^{-}	**2005**	**Grassland**	Dactyle Ludac + Fétuque Soni + Ray-grass Milca	20/04/2005	-	1.00	0	0
	2006						30	5834
	2007						30	5929
	2008						30	4864
	2009						30	2543
	2010						30	1687
	2011	**Maize**	PR38V12 PIONER	18/04/2011	27/09/2011	1.20	36	7042
	2012	**Wheat**	Caphorn	16/11/2011	24/07/2012	1.15	160	5904
	2013	**Barley**	Limpid	16/10/2012	16/07/2013	1.15	90	5677
G	**2005**	**Grassland**	Dactyle Ludac + Fétuque Soni + Ray-grass Milca	20/04/2005	-	1.00	0	0
	2006						170	11035
	2007						380	15531
	2008						330	12609
	2009						230	9173
	2010						210	5303
	2011						120	4436
	2012						210	5767
	2013						220	10690

4. CAPÍTULO IV

4.1 Conclusões gerais

4.2 Referências bibliográficas

4.1 CONCLUSÕES GERAIS

Utilizando-se 10 anos de dados de um sistema integrado de produção agropecuária foi possível detectar padrões de comportamento nas relações entre as variáveis de pasto e animal, mesmo existindo influencia dos anos avaliados. Para se atingir ganhos satisfatórios na produção animal, sem afetar negativamente outros parâmetros do sistema, sugerimos que o manejo seja feito mantendo-se o pasto com 30 cm de altura.

Na condição de solo e clima do Centro-Oeste da França, a introdução de pastagem na rotação de culturas diminui a concentração de nitrato na água drenada. A redução nas perdas de nitrogênio é proporcional ao tempo de permanência da pastagem na rotação. A destruição de pastagens por aração e o cultivo com culturas de grãos não aumentam a lixiviação de nitrogênio. Porém, em regiões onde a disponibilidade de água depende fortemente de recarga de aquíferos no inverno, deve-se fazer um balanço entre a vantagem da introdução de pastagens no sistema de cultivo, que melhora a qualidade da água drenada e da possível desvantagem associada a uma redução no volume da água drenada.

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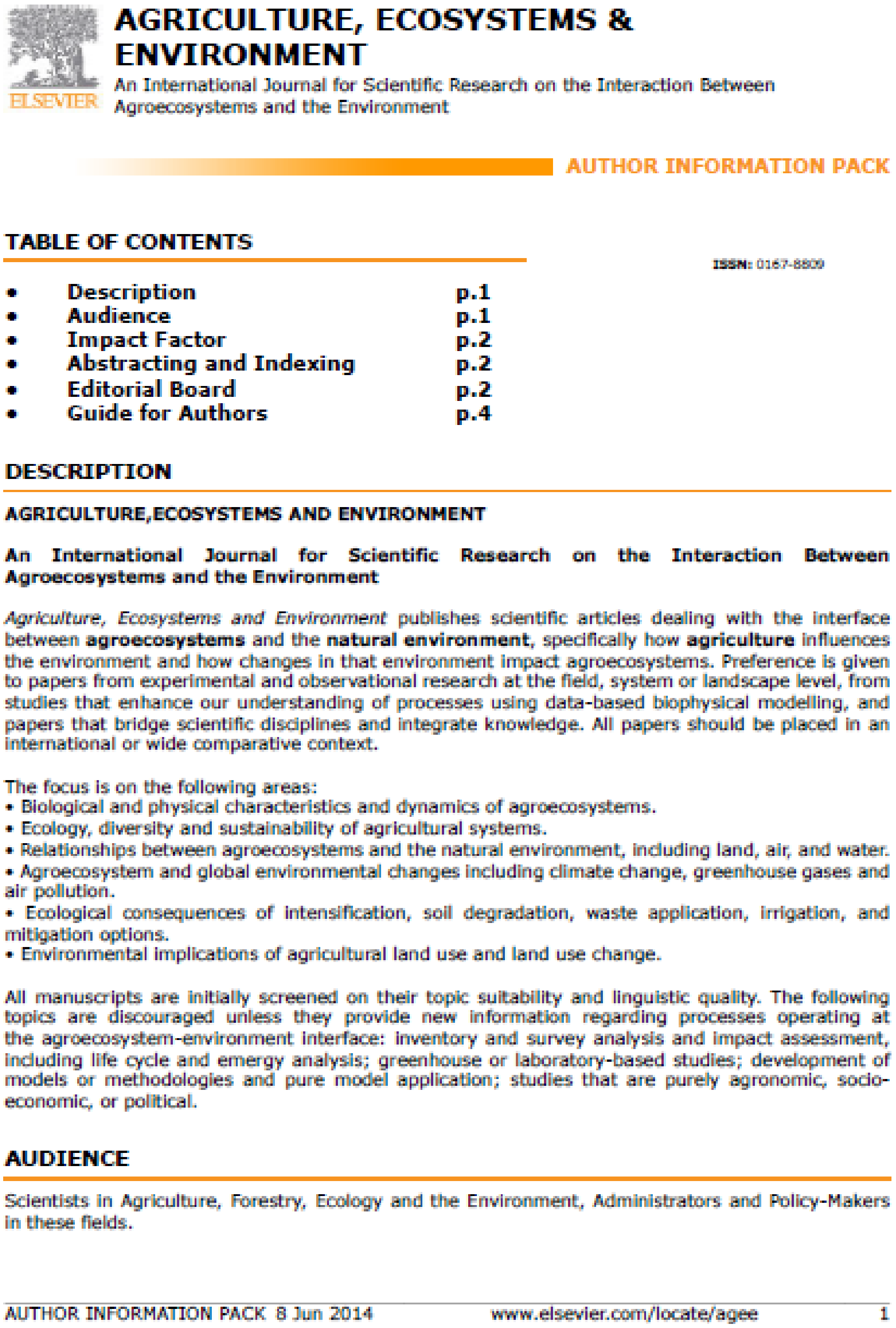
5. APÊNDICES

Apêndice 1. Normas utilizadas para escrever o Capítulo II.



AGRICULTURE, ECOSYSTEMS & ENVIRONMENT

An International Journal for Scientific Research on the Interaction Between Agroecosystems and the Environment

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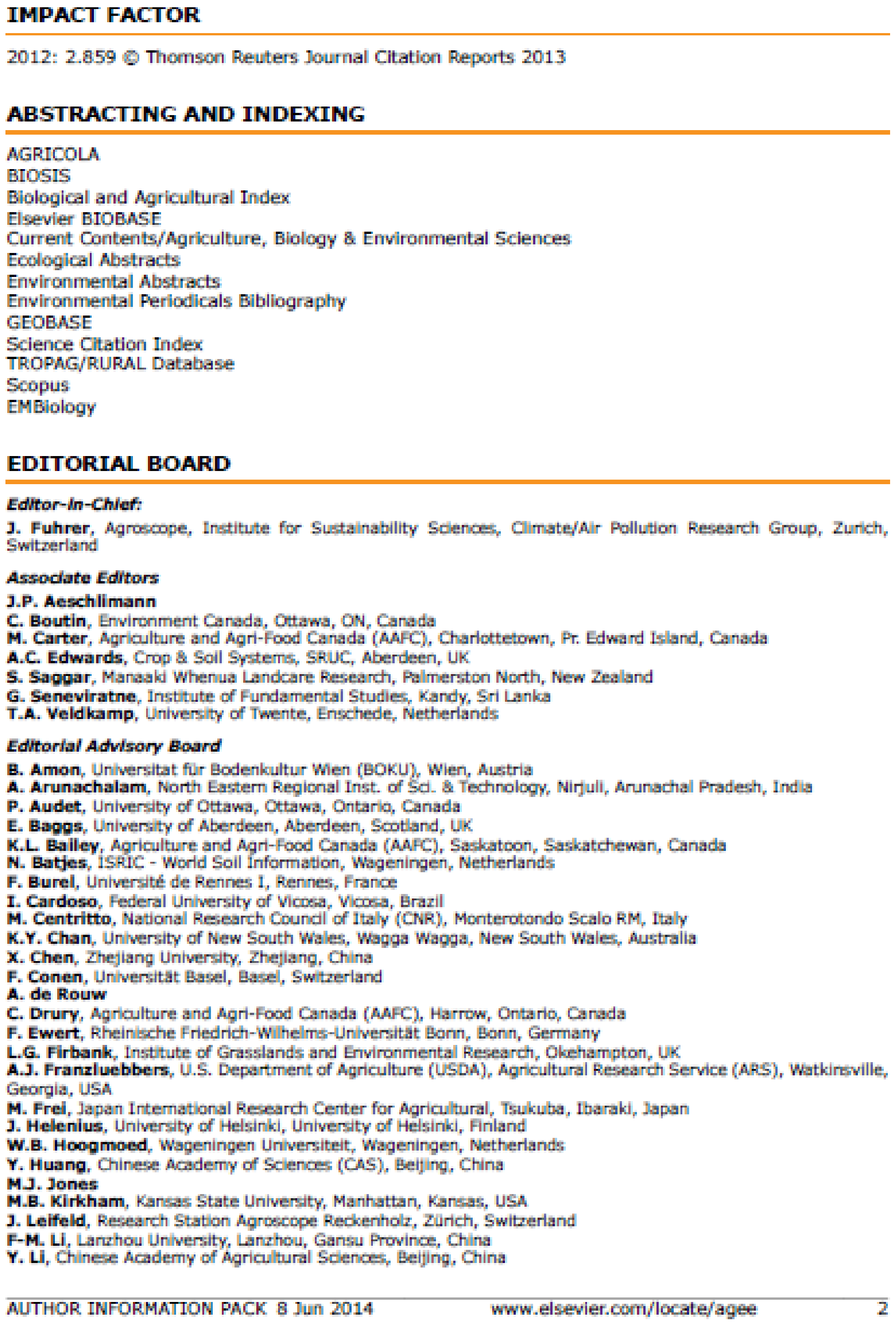

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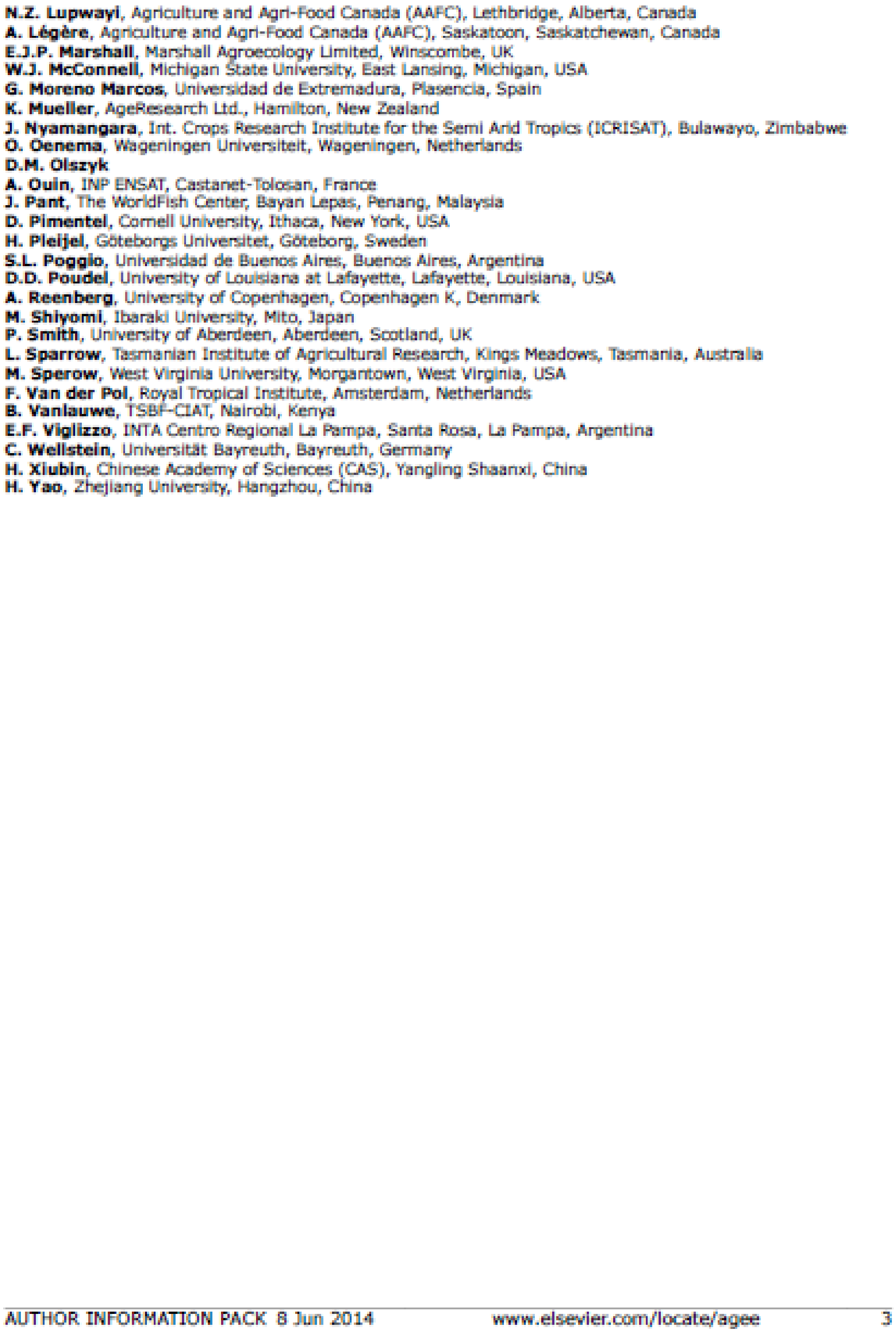

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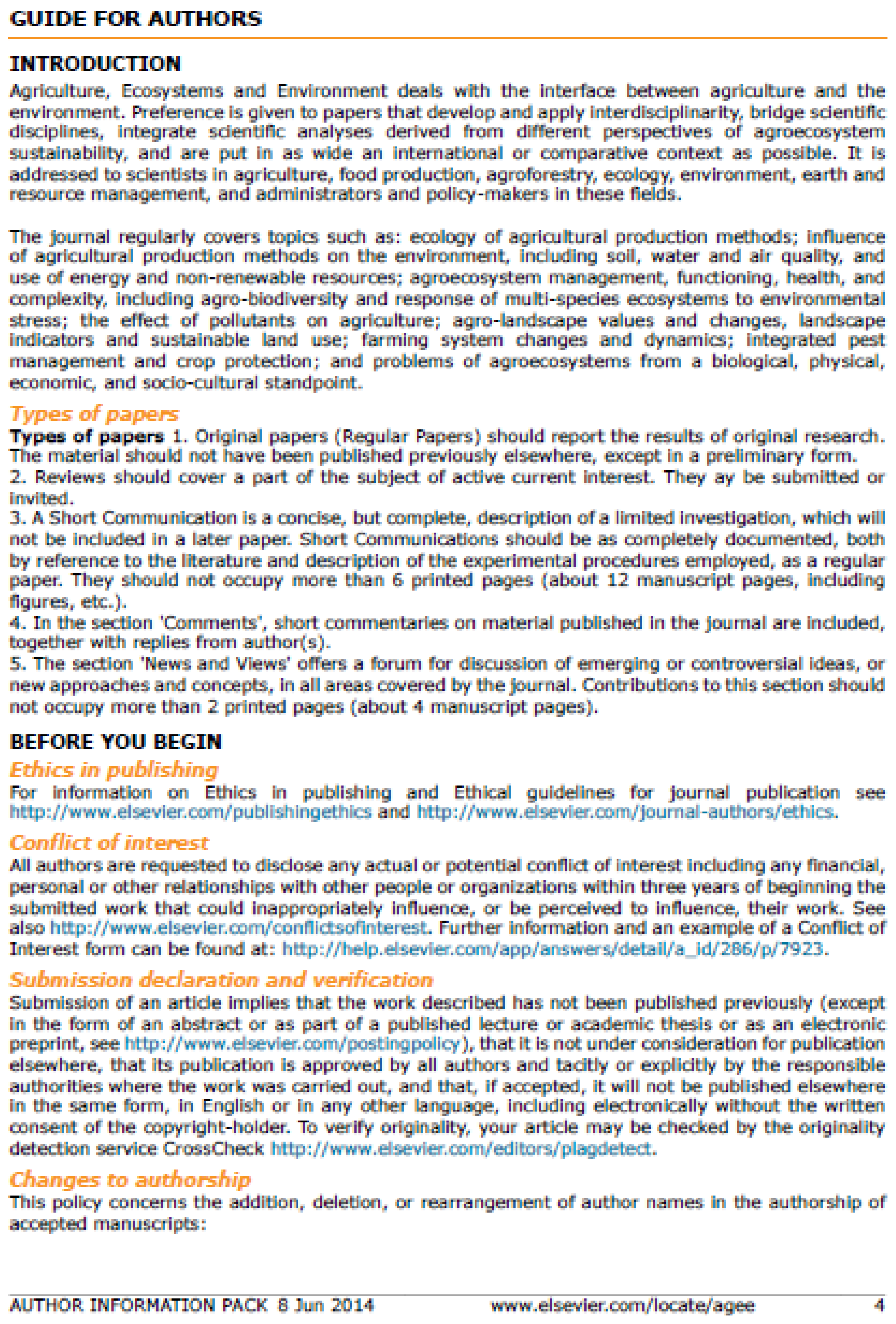

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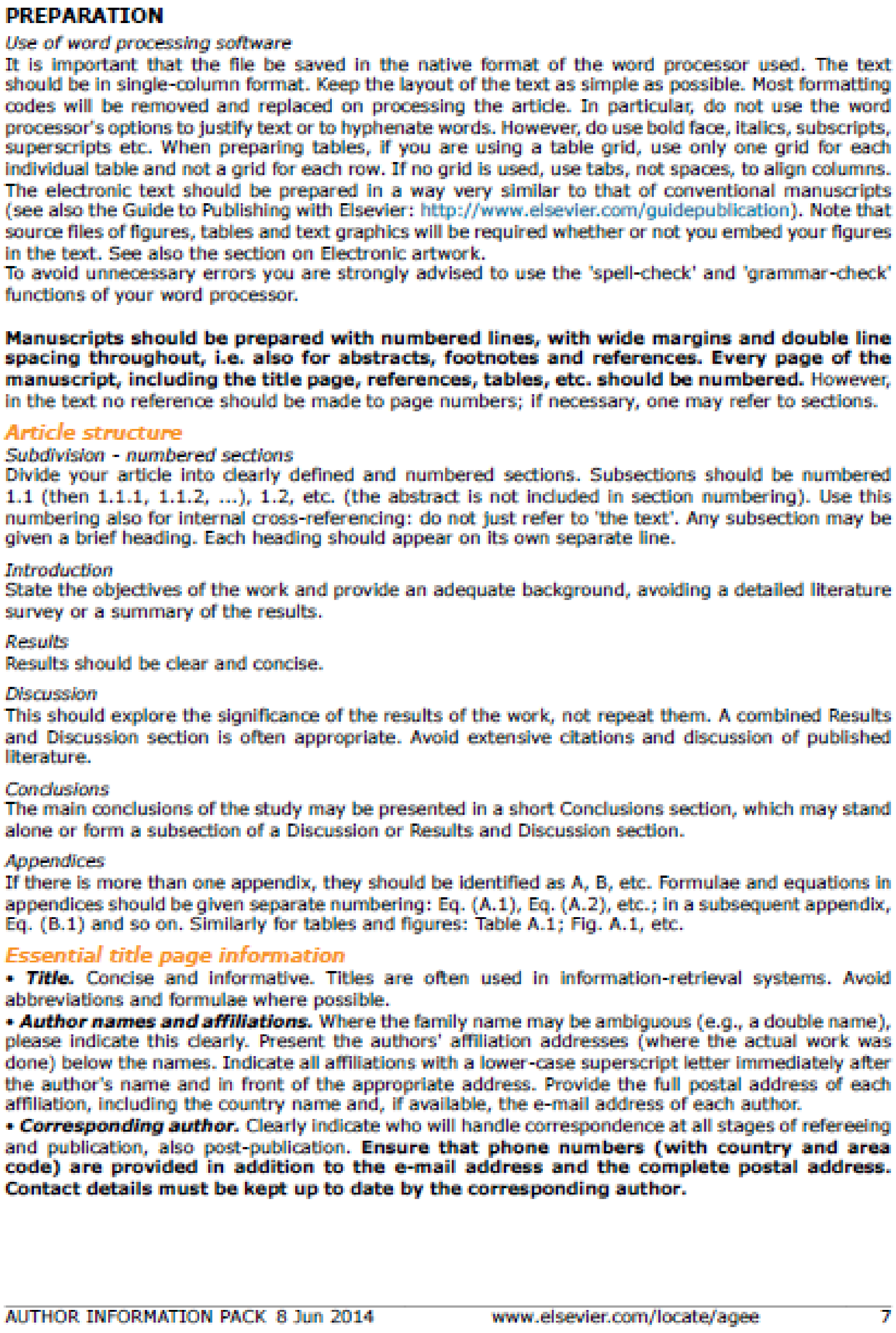

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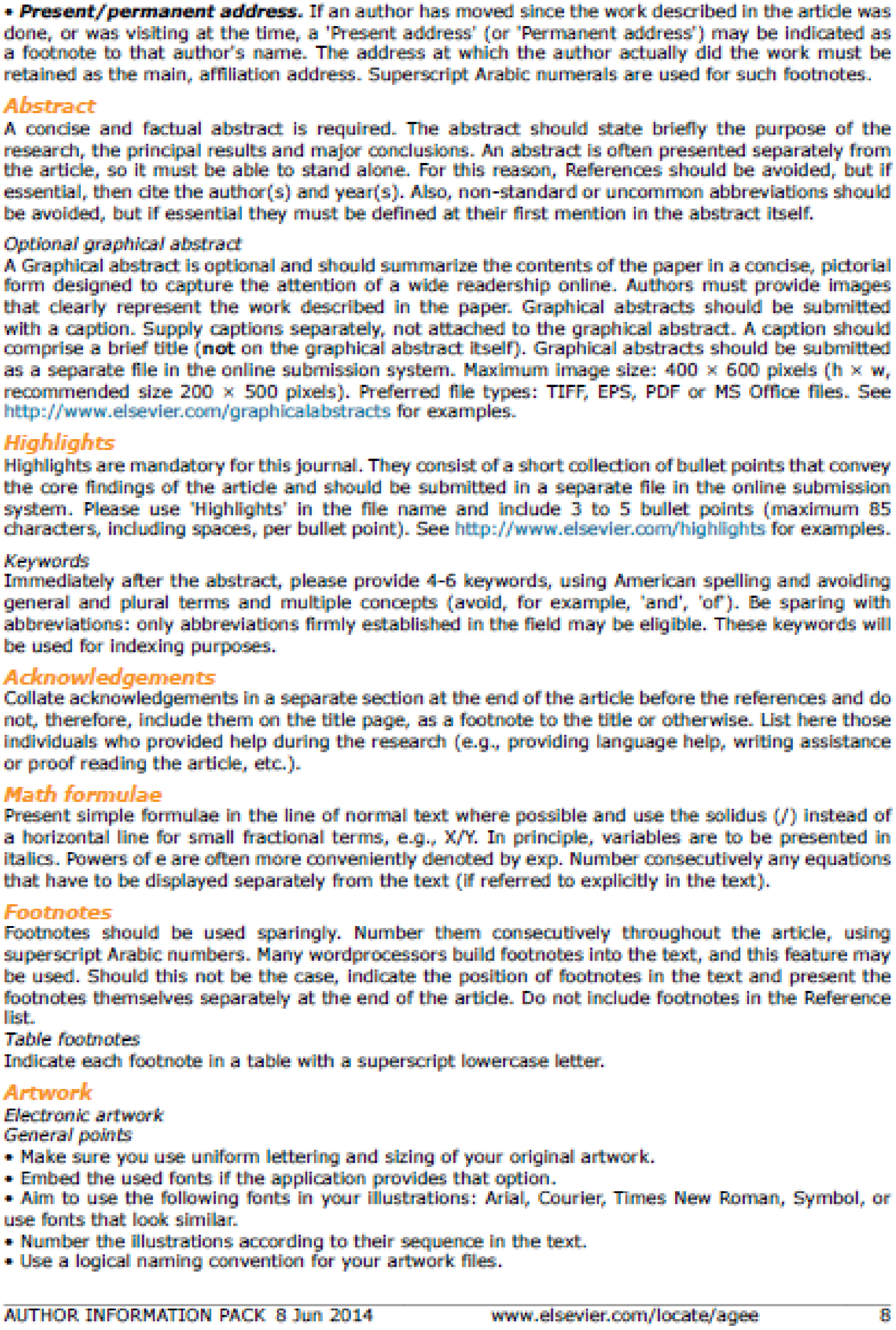

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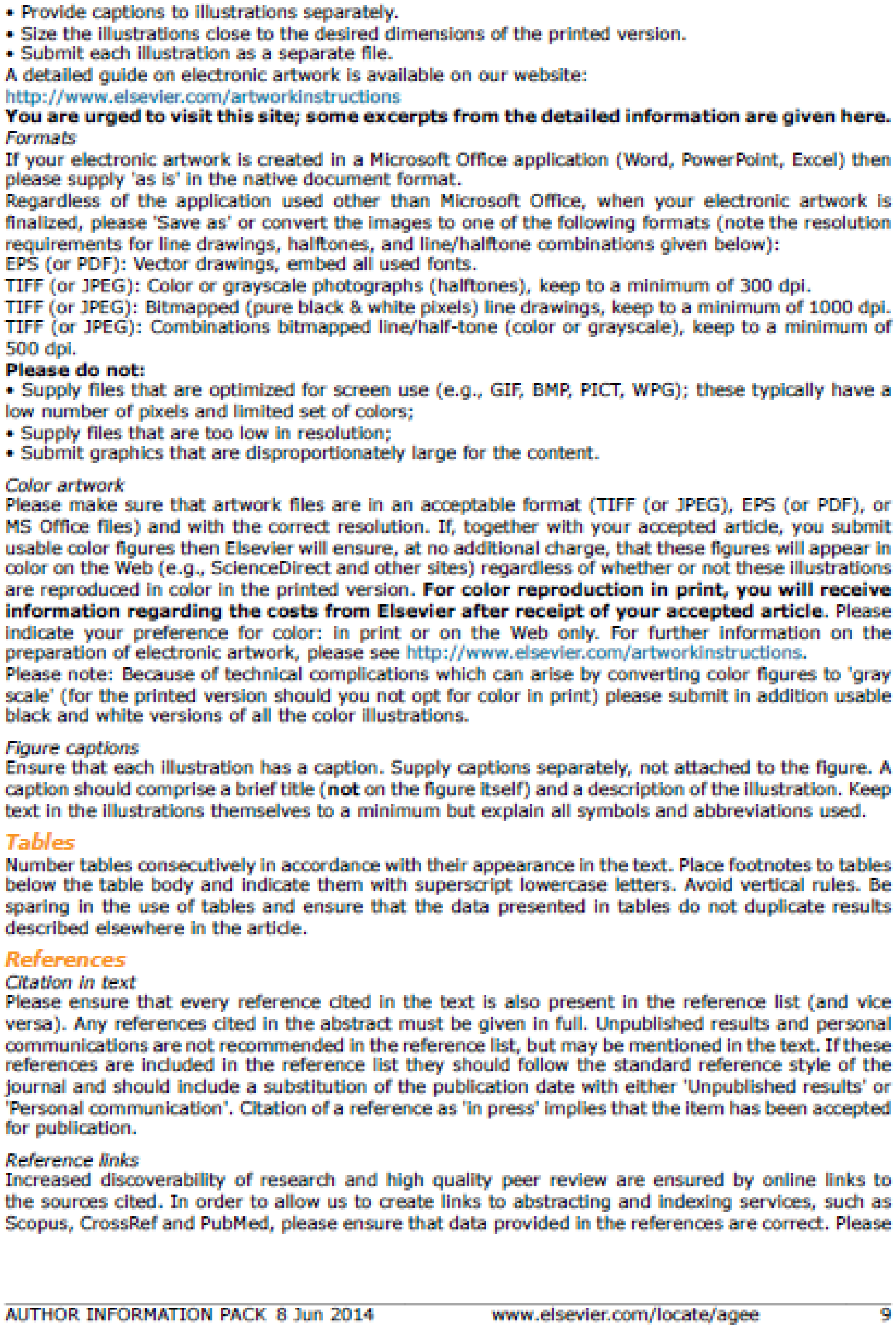

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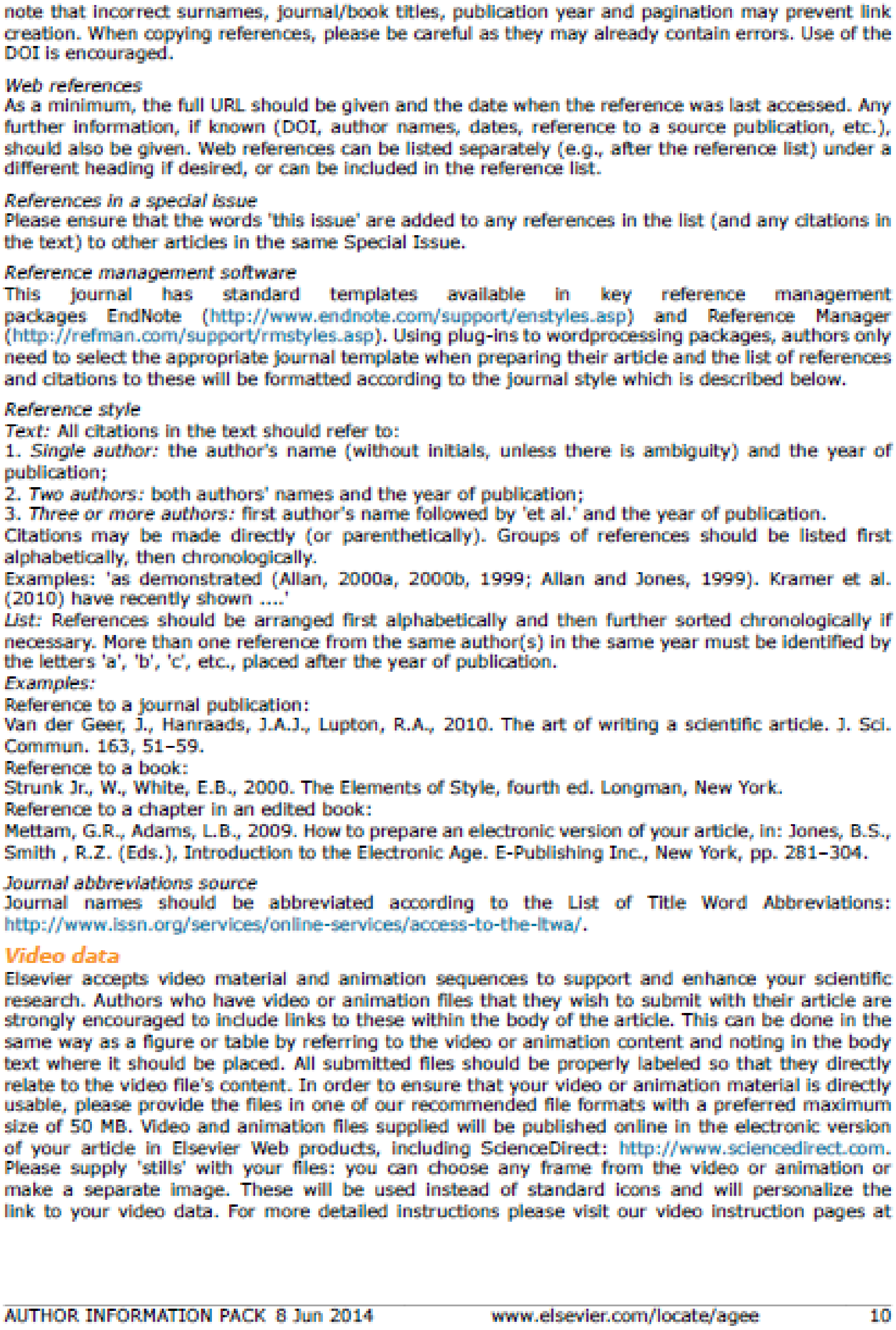

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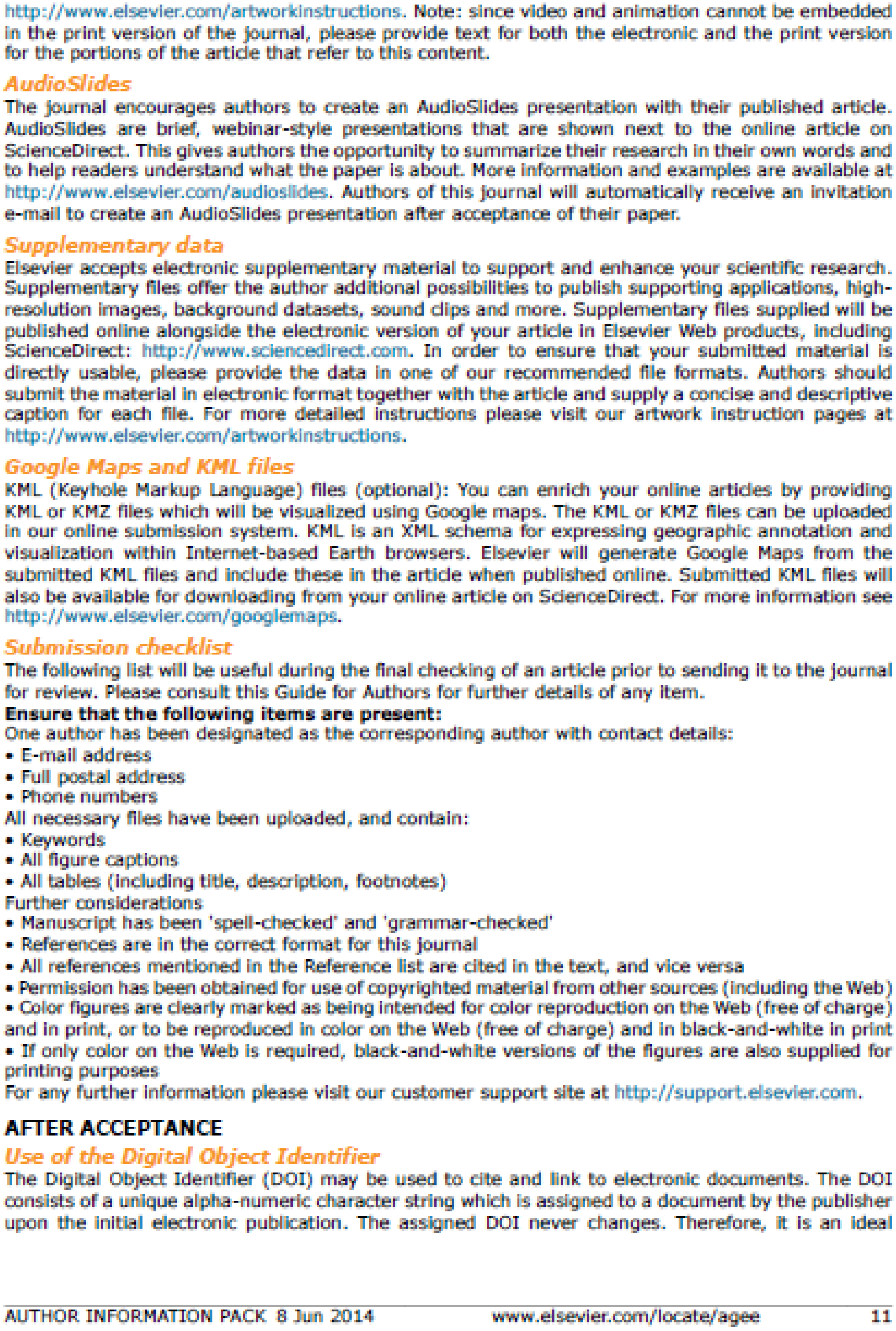

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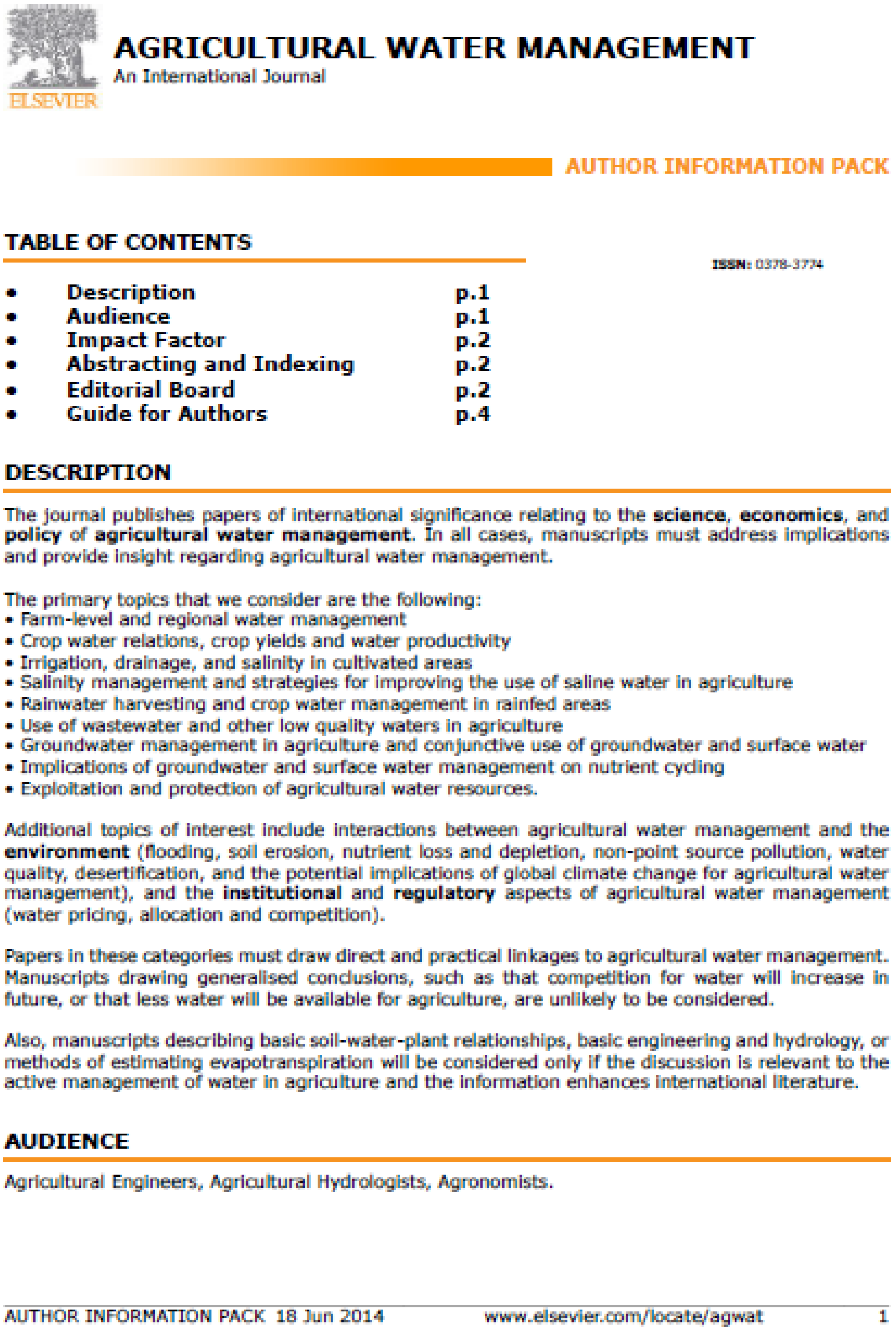

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DESCRIPTION

The journal publishes papers of international significance relating to the **science**, **economics**, and **policy** of **agricultural water management**. In all cases, manuscripts must address implications and provide insight regarding agricultural water management.

The primary topics that we consider are the following:
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- Rainwater harvesting and crop water management in rainfed areas
- Use of wastewater and other low quality waters in agriculture
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Also, manuscripts describing basic soil-water-plant relationships, basic engineering and hydrology, or methods of estimating evapotranspiration will be considered only if the discussion is relevant to the active management of water in agriculture and the information enhances international literature.

AUDIENCE

Agricultural Engineers, Agricultural Hydrologists, Agronomists.

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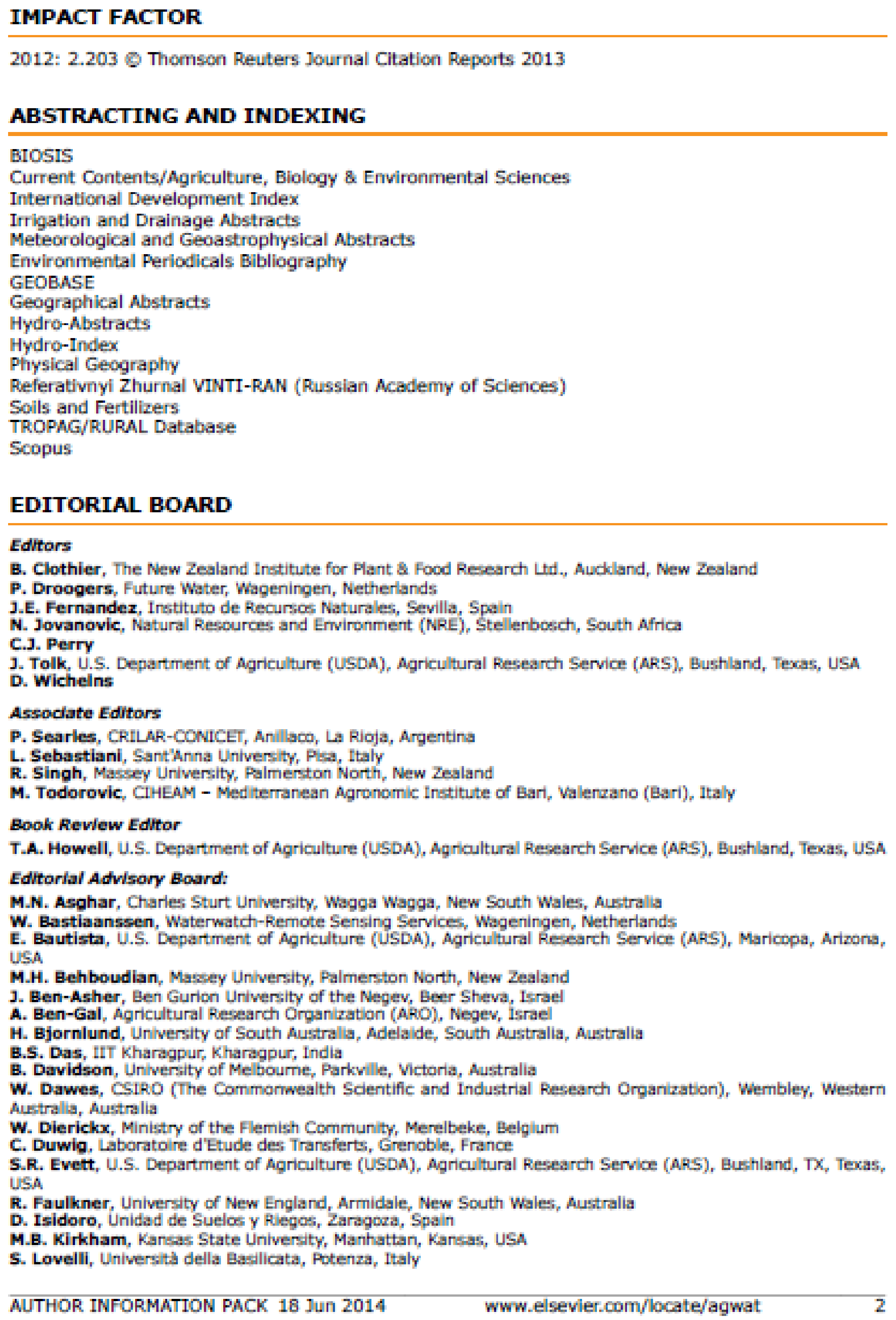

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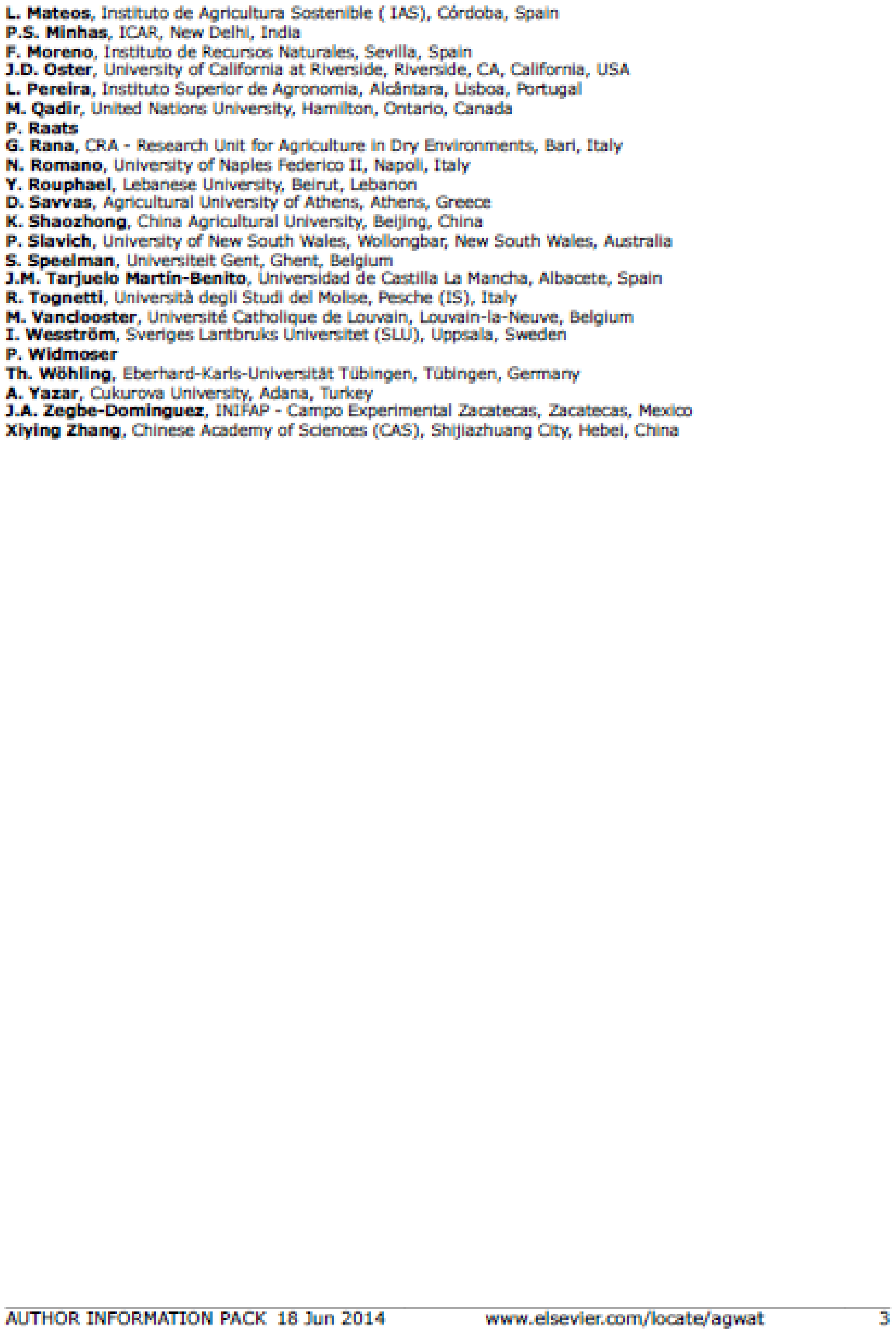

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GUIDE FOR AUTHORS

INTRODUCTION

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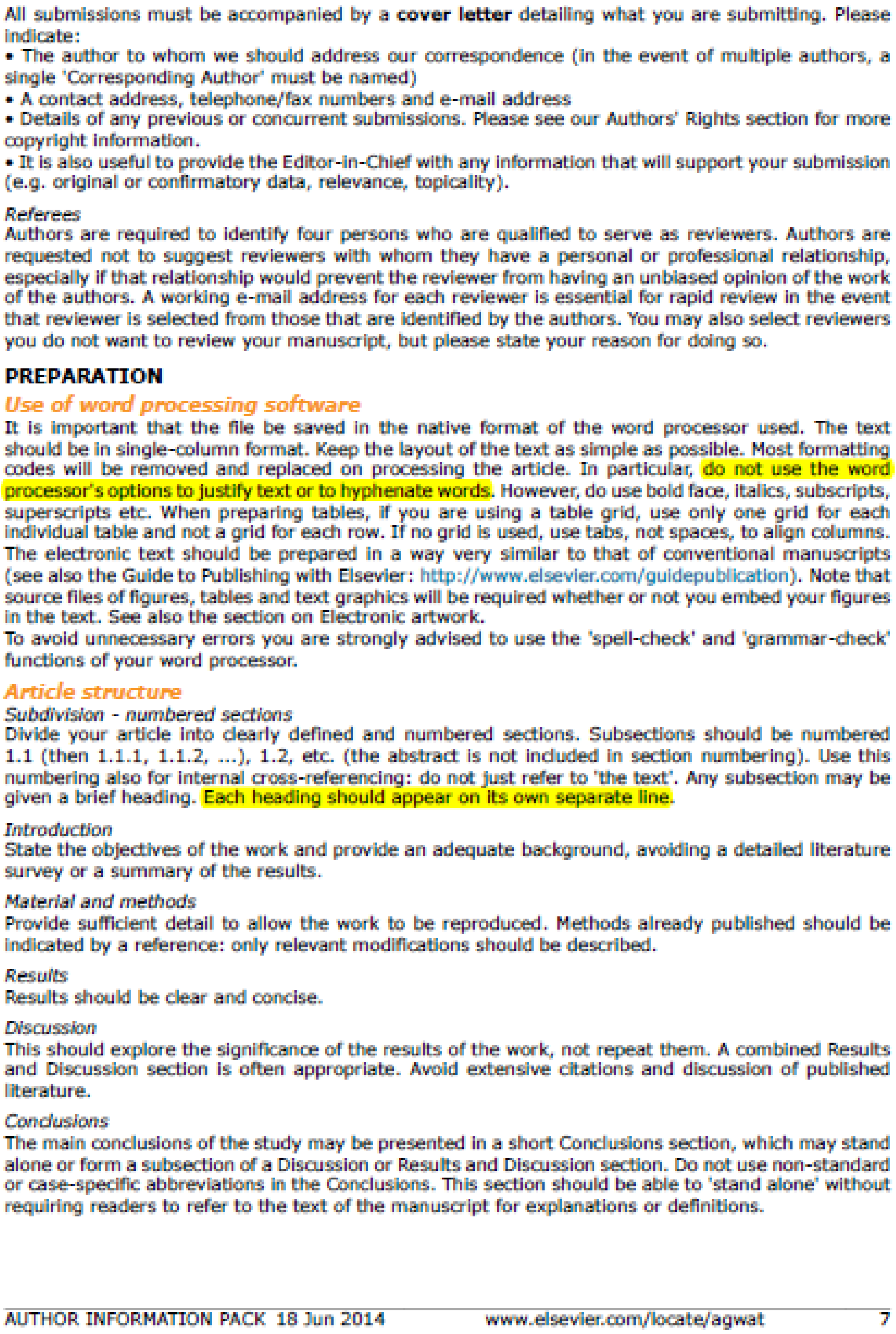

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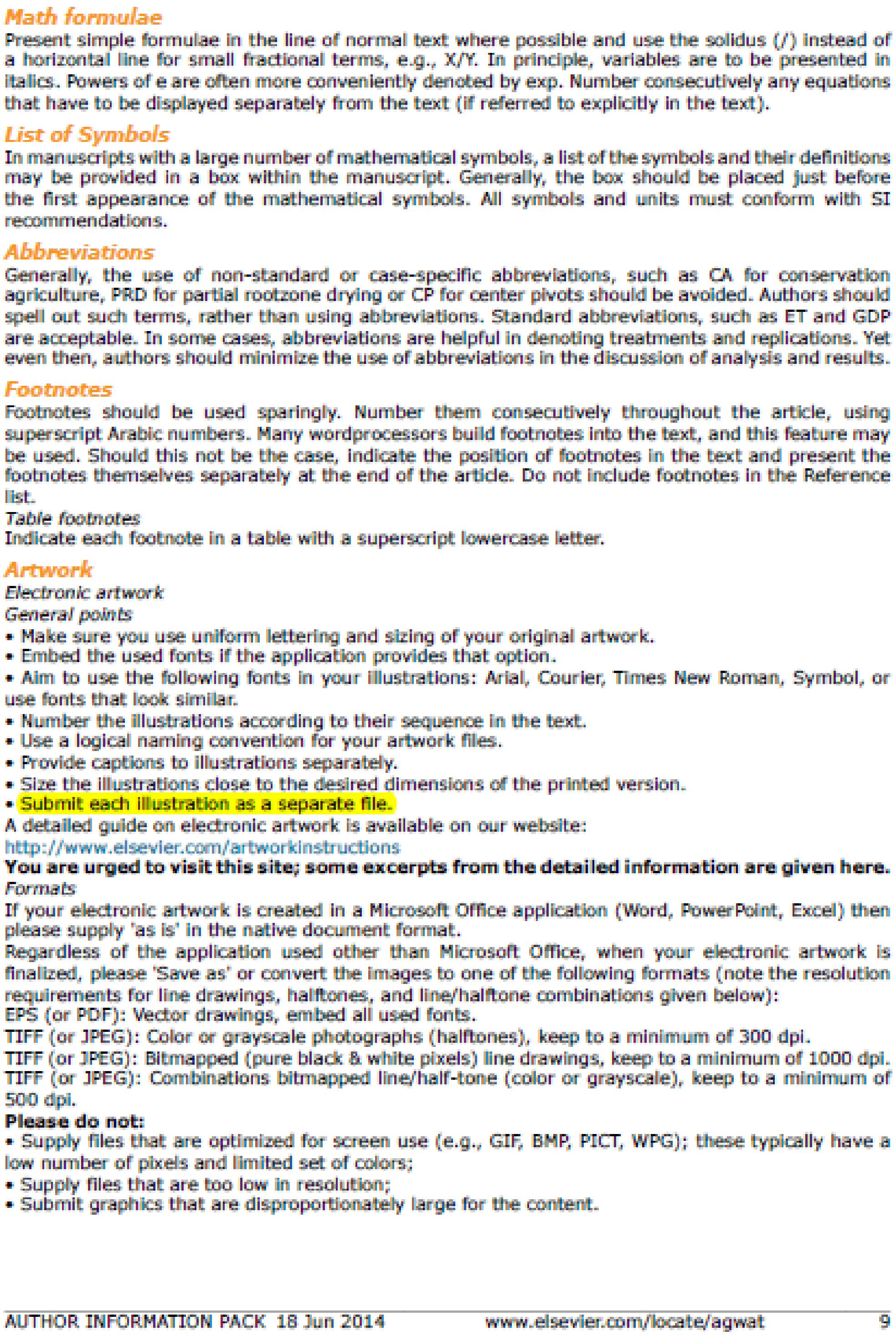

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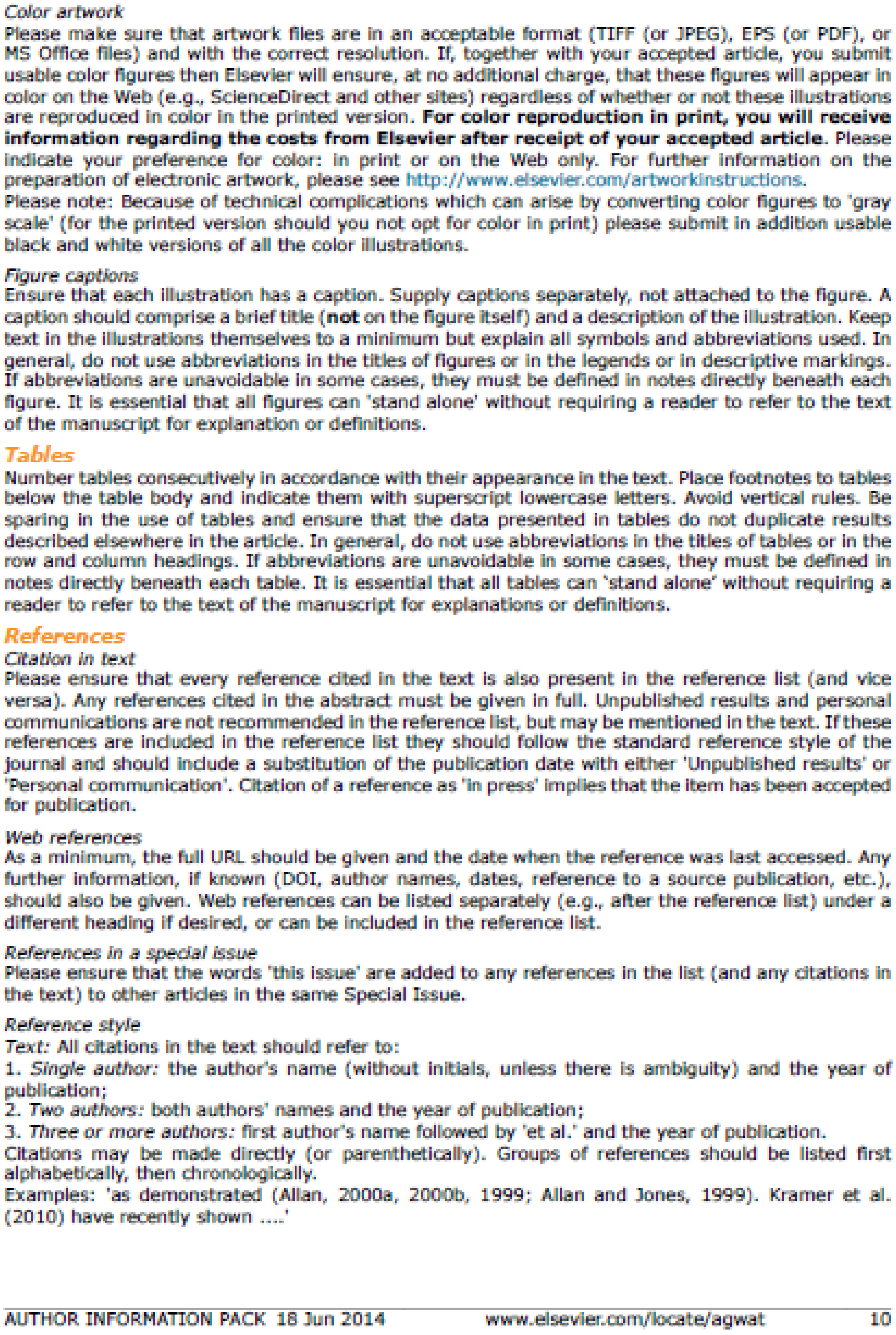

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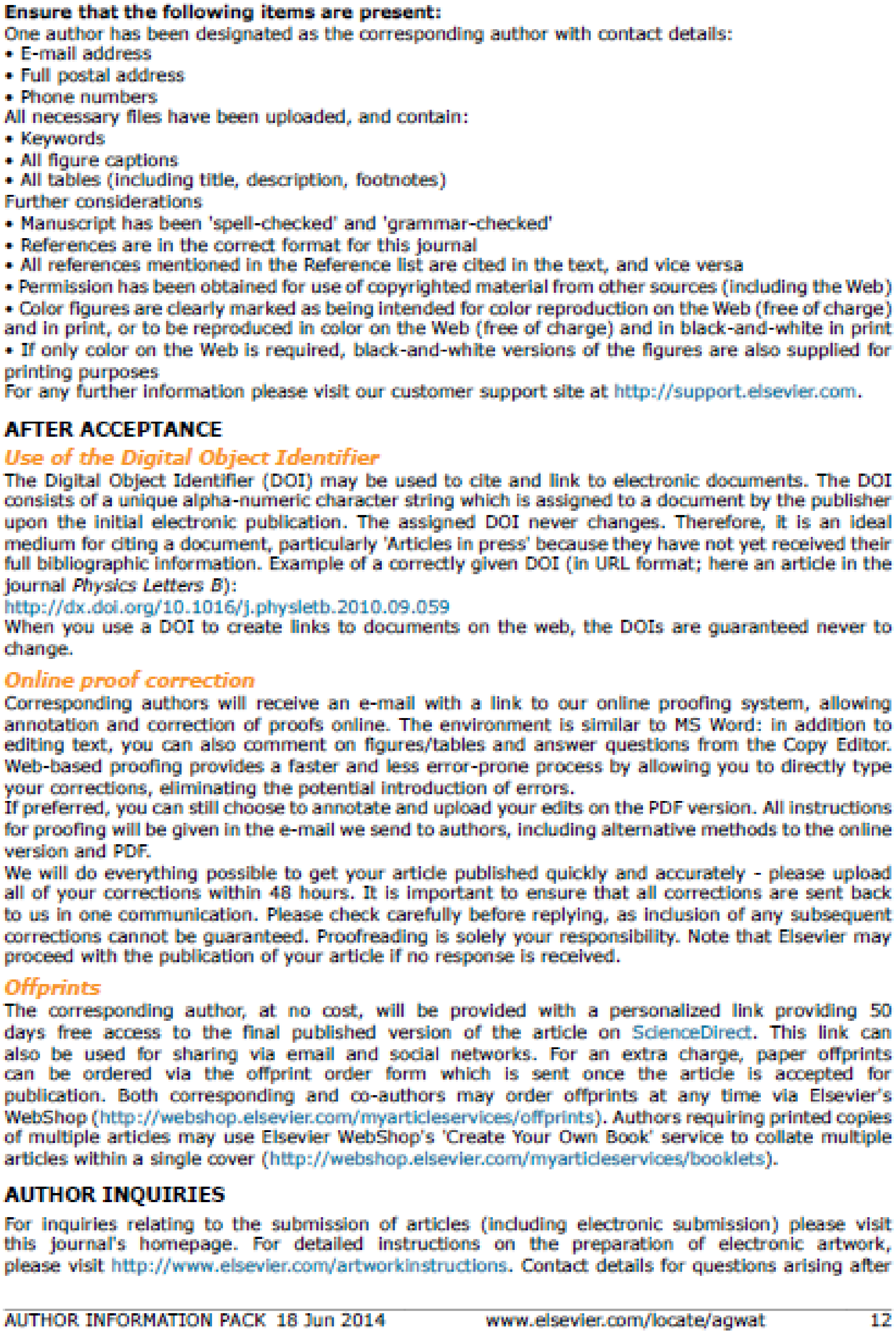

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Apêndice 3. Entrada de dados de massa de forragem (MF), massa de forragem inicial (MFI), taxa de acúmulo diário (TxAc), resíduo vegetal, produção total de matéria seca (PTMS) altura média real (Alt) para a altura de manejo de 10 cm – Capítulo II.

Tratamento	Bloco	Potreiro	Ano	MF	MFI	TxAc	Resíduo	PTMS	Alt
10	1	2	2001	1222		48,8	1272	6947	10,0
10	2	8	2001	1827		44,2	1480	6219	12,1
10	3	10	2001	1883		45,6	1750	6683	14,2
10	1	2	2002	1508		33,9	2030	5847	10,5
10	2	8	2002	1153		40,8	1580	6680	8,4
10	3	10	2002	1322		31,1	1570	5658	7,3
10	1	2	2003	1826		64,2		9247	15,6
10	2	8	2003	1911		46,5		8746	11,2
10	3	10	2003	1967		57,2		9438	15,2
10	1	2	2004	1491		23,2			13,1
10	2	8	2004	1336		57,6		8877	11,4
10	3	10	2004	1698		43,4			12,4
10	1	2	2005	1971		70,3	2520	10050	12,1
10	2	8	2005	2021		71,5		10211	12,4
10	3	10	2005	1828		50,6	2205	7377	11,7
10	1	2	2006	1128		37,6		5907,5	13,3
10	2	8	2006	1162		33,6		5511,8	11,8
10	3	10	2006	1443		36,4		6084,8	14,5
10	1	2	2007						12,4
10	2	8	2007						11,4
10	3	10	2007						10,8
10	1	2	2008	1305		48,4	1406	2707,476	15,7
10	2	8	2008	1086		54,6	1132	2364,743	13,6
10	3	10	2008	999		49,2	1178	2252,169	12,9
10	1	2	2009	1215		34,4	1386	4843,654	12,9
10	2	8	2009	1223		36,3	1264	5111,046	13,0
10	3	10	2009	1140		30,2	1341	4331,845	11,4
10	1	2	2010	1040		9,0	606	2332,804	10,7
10	2	8	2010	823		29,1	896	4629,999	9,5
10	3	10	2010	893		13,7	935	3164,292	12,2
10	1	2	2011	1082		35,6	1134	5083	12,6
10	2	8	2011	725		28,3	783	4193	10,0
10	3	10	2011	1040		36,4	1023	5733	13,1

Apêndice 4. Entrada de dados de ganho médio diário individual (GMD), ganho por área (Gha) e carga animal (CA) para a altura de manejo de 10 cm – Capítulo II.

Tratamento	Bloco	Potreiro	Ano	GMD	Gha	CA
10	1	2	2001	0,849	481	1382
10	2	8	2001	0,840	488	1467
10	3	10	2001	0,994	472	1229
10	1	2	2002	0,848	513	1168
10	2	8	2002	0,981	619	1254
10	3	10	2002	0,921	491	1159
10	1	2	2003	0,810	539	1422
10	2	8	2003		463	
10	3	10	2003	0,900	618	1703
10	1	2	2004	0,865	554	1296
10	2	8	2004		446	1276
10	3	10	2004	0,835	590	1268
10	1	2	2005	0,996	501	988
10	2	8	2005	0,868	572	1090
10	3	10	2005	1,018	471	1173
10	1	2	2006	0,880	616	1392
10	2	8	2006	0,700	566	1647
10	3	10	2006	0,710	654	1255
10	1	2	2007	0,822	470	1171
10	2	8	2007		344	1361
10	3	10	2007	0,743	471	1099
10	1	2	2008	0,760	469	1269
10	2	8	2008	0,689	490	1484
10	3	10	2008	0,770	525	1407
10	1	2	2009	0,848	483	1370
10	2	8	2009	0,730	491	1525
10	3	10	2009	0,908	614	1580
10	1	2	2010	0,768	324	1079
10	2	8	2010			1159
10	3	10	2010	0,734	388	1309
10	1	2	2011		479	818
10	2	8	2011	0,944	414	970
10	3	10	2011	0,980	484	917

Apêndice 5. Entrada de dados de massa de forragem (MF), massa de forragem inicial (MFI), taxa de acúmulo diário (TxAc), resíduo vegetal, produção total de matéria seca (PTMS) altura média real (Alt) para a altura de manejo de 20 cm – Capítulo II.

Tratamento	Bloco	Potreiro	Ano	MF	MFI	TxAc	Resíduo	PTMS	Alt
20	1	4	2001	2527		39,7	4400	5668	19,6
20	2	7	2001	2922		56,2	4304	7783	21,4
20	3	9	2001	2447		46,6	1928	6480	24,3
20	1	4	2002	2162		32,5	4080	5819	16,5
20	2	7	2002	2019		40,9	3370	5565	14,6
20	3	9	2002	2296		57,8	4010	8769	18,2
20	1	4	2003	2754		74,4		11531	24,8
20	2	7	2003	2802		62,5		10458	23,5
20	3	9	2003	3048		45,6		8533	23,9
20	1	4	2004	1900		38,5		6694	18,3
20	2	7	2004	1942		62,1		9558	17,5
20	3	9	2004	1838		54,6		8179	20,5
20	1	4	2005	2744		51,7	3728	8428	20,7
20	2	7	2005	2740		15,0	5147	7337	21,2
20	3	9	2005	2737		29,8	4043	6041	20,7
20	1	4	2006	2249		27,3		5027,4	21,3
20	2	7	2006	1659		43,0		6962,5	20,2
20	3	9	2006	1827		38,4		6127,4	19,8
20	1	4	2007						21,6
20	2	7	2007						21,2
20	3	9	2007						26,6
20	1	4	2008	2295		39,9	2867	3632,814	26,3
20	2	7	2008	1733		44,6	2348	3192,068	21,3
20	3	9	2008	1765		44,8	2016	3122,741	20,1
20	1	4	2009	2022		59,5	3282	7698,791	22,0
20	2	7	2009	1850		30,0	2729	4646,443	20,6
20	3	9	2009	2076		40,1	3724	5494,497	21,5
20	1	4	2010	884		28,1	930	4847,655	15,1
20	2	7	2010	1517		22,9	1621	4313,137	18,3
20	3	9	2010	1117		15,6	2101	3350,649	17,5
20	1	4	2011	2547		50,9	2860	8841	26,7
20	2	7	2011	2103		27,7	4146	4699	24,1
20	3	9	2011	1745		47,8	2447	7509	21,3

Apêndice 6. Entrada de dados de ganho médio diário individual (GMD), ganho por área (Gha) e carga animal (CA) para a altura de manejo de 20 cm – Capítulo II.

Tratamento	Bloco	Potreiro	Ano	GMD	Gha	CA
20	1	4	2001	1,077	309	786
20	2	7	2001	1,054	276	752
20	3	9	2001	0,958	347	961
20	1	4	2002	1,328	573	933
20	2	7	2002	1,103	483	956
20	3	9	2002	1,222	555	916
20	1	4	2003	1,150	514	1136
20	2	7	2003	0,920	315	1210
20	3	9	2003	0,960	491	
20	1	4	2004	1,119	466	952
20	2	7	2004	1,090	517	1071
20	3	9	2004	1,199	486	841
20	1	4	2005	1,308	385	675
20	2	7	2005	1,239	395	864
20	3	9	2005	1,170	376	836
20	1	4	2006	1,060	428	804
20	2	7	2006	0,980	483	948
20	3	9	2006	1,120	576	1047
20	1	4	2007	1,141	520	998
20	2	7	2007	1,023	533	1168
20	3	9	2007	0,884	450	987
20	1	4	2008	0,930	375	890
20	2	7	2008	0,943	375	845
20	3	9	2008		507	1006
20	1	4	2009	0,746	348	801
20	2	7	2009	0,968	434	1004
20	3	9	2009	0,962	387	875
20	1	4	2010		417	918
20	2	7	2010	1,004	373	916
20	3	9	2010	1,003	335	918
20	1	4	2011		358	709
20	2	7	2011	0,767	385	894
20	3	9	2011	0,843	285	652

Apêndice 7. Entrada de dados de massa de forragem (MF), massa de forragem inicial (MFI), taxa de acúmulo diário (TxAc), resíduo vegetal, produção total de matéria seca (PTMS) altura média real (Alt) para a altura de manejo de 30 cm – Capítulo II.

Tratamento	Bloco	Potreiro	Ano	MF	MFI	TxAc	Resíduo	PTMS	Alt
30	1	3	2001	3604		60,3	6155	8283	26,6
30	2	5	2001	3710		43,3	6262	6466	24,9
30	3	11	2001	3874		54,1	6544	7240	31,4
30	1	3	2002	3040		48,4	4770	7774	27,1
30	2	5	2002	3095		50,4	5110	7719	27,0
30	3	11	2002	3177		41,3	4870	7133	27,0
30	1	3	2003	4305					38,8
30	2	5	2003	4058		56,5		9655	
30	3	11	2003	4049		68,6		11200	37,8
30	1	3	2004	2745		56,0		8930	26,8
30	2	5	2004	3090		39,4		6806	29,0
30	3	11	2004	2416		48,0		7871	28,7
30	1	3	2005	3306		45,8	5555	8422	28,2
30	2	5	2005	3499		38,7	5027	8155	29,8
30	3	11	2005	3446		47,4	6740	9227	30,0
30	1	3	2006	2850		33,8		6319,2	29,8
30	2	5	2006	3021		40,6		6111,6	31,4
30	3	11	2006	3046		31,2		5403,9	30,2
30	1	3	2007						36,2
30	2	5	2007						36,4
30	3	11	2007						34,5
30	1	3	2008	2571		33,3	4584	4055,941	30,4
30	2	5	2008	3335		47,2	3497		35,0
30	3	11	2008	2487		44,6	3257	3564,528	30,8
30	1	3	2009	2716		45,5	4320	6183,535	29,7
30	2	5	2009	2741		61,9	4761	8318,922	31,1
30	3	11	2009	2663		62,0	4826	8030,188	29,1
30	1	3	2010	2130		29,6	3397	5247,186	30,6
30	2	5	2010	2509		43,7	3592	7205,18	33,2
30	3	11	2010	1632		20,7	3171	4220,685	25,7
30	1	3	2011	1911		10,0	3047	1958	25,6
30	2	5	2011	2194		59,3	3918	8661	27,5
30	3	11	2011	1647		30,9	2381	5476	23,2

Apêndice 8. Entrada de dados de ganho médio diário individual (GMD), ganho por área (Gha) e carga animal (CA) para a altura de manejo de 30 cm – Capítulo II.

Tratamento	Bloco	Potreiro	Ano	GMD	Gha	CA
30	1	3	2001	1,253	292	632
30	2	5	2001	1,096	254	637
30	3	11	2001	0,994		374
30	1	3	2002	1,152	311	539
30	2	5	2002	1,266	301	498
30	3	11	2002	1,157	290	501
30	1	3	2003	1,160	206	670
30	2	5	2003	1,110	260	540
30	3	11	2003	1,140	338	772
30	1	3	2004	1,363	360	626
30	2	5	2004	1,134	278	604
30	3	11	2004	1,229	324	590
30	1	3	2005	1,092	263	425
30	2	5	2005	1,178	270	497
30	3	11	2005	1,122	330	510
30	1	3	2006	1,020	263	506
30	2	5	2006	1,160	377	706
30	3	11	2006	1,050	343	613
30	1	3	2007	1,059	383	743
30	2	5	2007	0,994	348	662
30	3	11	2007		338	833
30	1	3	2008	1,030	279	592
30	2	5	2008	0,943	284	705
30	3	11	2008	0,930		736
30	1	3	2009	0,905	334	700
30	2	5	2009	0,879	299	624
30	3	11	2009	1,083	379	765
30	1	3	2010	1,076	277	642
30	2	5	2010	1,280	318	585
30	3	11	2010		358	702
30	1	3	2011	1,360	360	597
30	2	5	2011	1,138	295	549
30	3	11	2011	1,122	316	590

Apêndice 9. Entrada de dados de massa de forragem (MF), massa de forragem inicial (MFI), taxa de acúmulo diário (TxAc), resíduo vegetal, produção total de matéria seca (PTMS) altura média real (Alt) para a altura de manejo de 40 cm – Capítulo II.

Tratamento	Bloco	Potreiro	Ano	MF	MFI	TxAc	Resíduo	PTMS	Alt
40	1	1	2001	4268		53,2	6464	7354	35,6
40	2	6	2001	3838		48,3	6296	6384	32,8
40	3	12	2001	3938		46,5	6936	6395	34,1
40	1	1	2002	3662		37,8	5930	6333	35,8
40	2	6	2002	3601		32,9	5540	5866	31,6
40	3	12	2002	3389		27,0	5110	7125	31,6
40	1	1	2003			80,1		11190	49,5
40	2	6	2003	3940					46,9
40	3	12	2003	4305		50,6		8814	43,5
40	1	1	2004	3388		67,3		10008	31,2
40	2	6	2004	3008		37,4		6357	31,6
40	3	12	2004	3366		44,5		6903	33,2
40	1	1	2005	4084		61,4		9207	36,5
40	2	6	2005	3895		35,5	6277	6498	34,8
40	3	12	2005	3942		41,6	6056	7570	36,9
40	1	1	2006	4072		41,1		7131,1	40,0
40	2	6	2006	3887		47,7		7452,8	38,5
40	3	12	2006	3803		62,1		9107	38,1
40	1	1	2007						45,4
40	2	6	2007						43,7
40	3	12	2007						40,9
40	1	1	2008	3159		47,7	5735	4910,181	45,7
40	2	6	2008	2760		43,0	4560	4385,317	40,1
40	3	12	2008	2831		56,0	4001	4255,538	37,4
40	1	1	2009	3283		54,1	6269	7536,534	36,9
40	2	6	2009	3380		80,1	6630	10337,14	37,3
40	3	12	2009	3187		58,1	5837	7641,991	34,7
40	1	1	2010	3377		54,2	4268	8597,496	43,3
40	2	6	2010	3177		46,8	5188	7797,884	40,9
40	3	12	2010	2467		34,9	5397	6146,864	36,3
40	1	1	2011	3117		49,8	5150	8780	35,1
40	2	6	2011	3237		32,8	5207	5643	33,8
40	3	12	2011	2572		39,8	4207	6316	32,2

Apêndice 10. Entrada de dados de ganho médio diário individual (GMD), ganho por área (Gha) e carga animal (CA) para a altura de manejo de 40 cm – Capítulo II.

Tratamento	Bloco	Potreiro	Ano	GMD	Gha	CA
40	1	1	2001	1,077	101	246
40	2	6	2001	1,154	115	276
40	3	12	2001	1,035	147	353
40	1	1	2002	1,078	128	271
40	2	6	2002	1,095	155	294
40	3	12	2002	1,024	178	346
40	1	1	2003	1,150	138	281
40	2	6	2003	1,070	154	338
40	3	12	2003	1,140	168	380
40	1	1	2004	1,120	197	375
40	2	6	2004	1,338	207	396
40	3	12	2004	1,169	201	420
40	1	1	2005	1,055	141	292
40	2	6	2005	1,135	165	286
40	3	12	2005	1,106	196	366
40	1	1	2006	0,990	139	279
40	2	6	2006	1,300	176	260
40	3	12	2006	1,160	211	360
40	1	1	2007	0,921	139	303
40	2	6	2007	0,997	179	351
40	3	12	2007	1,079	236	380
40	1	1	2008	0,888	160	394
40	2	6	2008		140	392
40	3	12	2008	0,926	168	374
40	1	1	2009	1,225	165	296
40	2	6	2009	1,000	169	371
40	3	12	2009	1,060	199	424
40	1	1	2010	1,171	155	271
40	2	6	2010	1,182	180	374
40	3	12	2010	1,081	189	399
40	1	1	2011	1,137	184	236
40	2	6	2011	1,251	238	393
40	3	12	2011	1,304	267	442

6. VITA

Taise Robinson Kunrath nasceu em Porto Alegre, aos 9 dias do mês de setembro de 1979. Filha de Carlos Fernando Kunrath e Tais Robinson Kunrath. Realizou seus estudos de ensino fundamental na Escola São Luiz e o ensino médio na ACM - Associação Cristã de Moços, localizados na mesma cidade. Em 2001, formou-se no Curso Técnico em Biotecnologia da Universidade Federal do Rio Grande do Sul. Em 2002, ingressou no curso de Agronomia da mesma universidade, onde desenvolveu atividades de pesquisa junto ao Departamento de Plantas Forrageiras e Agrometeorologia (DPFA). Em 2003 foi bolsista de iniciação científica com bolsa PROPESQ no Departamento de Botânica/UFRGS e FAPERGS na Fundação de Pesquisa Agropecuária do estado do Rio Grande do Sul (FEPAGRO) de 2004 à 2006 e no DPFA/UFRGS em 2007 e 2008. Concluiu a faculdade de Agronomia em dezembro de 2008. Em 2009 ingressou no curso de Mestrado junto ao Programa de Pós-graduação em Zootecnia da Universidade Federal do Rio Grande do Sul, na área de concentração Plantas Forrageiras, com bolsa CAPES, recebendo o grau de Mestre em Zootecnia em fevereiro de 2011. Em dezembro de 2010 foi aprovada no Processo Seletivo do Departamento de Zootecnia/UFRGS na área de concentração Plantas Forrageiras, para o Curso de Doutorado. Entre outubro de 2012 e outubro de 2013, permaneceu em doutorado sanduíche no INRA/Lusignan na França sob orientação dos pesquisadores Jean-Louis Durand e Gilles Lemaire. Em agosto de 2014, submeteu esta tese para apreciação dos pares e julgamento ao título de Doutora em Zootecnia.