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ANÁLISE MULTIFRACTAL DE PLANTAS-DANINHAS EM SISTEMA DE SEMEADURA DIRETA

DANIEL MARTINS DA SILVA

São Luís – MA
2023

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Tese de doutorado apresentada ao Curso de Doutorado do Programa de Pós-Graduação em Biodiversidade e Biotecnologia – Rede BIONORTE, na Universidade Federal do Maranhão, como requisito parcial para a obtenção do Título de Doutor em Biodiversidade e Biotecnologia.

Orientador: Prof. Dr. Glécio Machado Siqueira

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RESUMO

As plantas-daninhas apresentam alta variabilidade espacial, possuindo comportamento de infestação em manchas ou reboleiras, com heterogeneidade em escalas que podem ser avaliadas por meio de análise multifractal. Assim, objetivou-se avaliar a variabilidade espacial de plantas-daninhas por meio de análise multifractal em sistema de semeadura direta. Os objetivos específicos foram: averiguar a dominância de plantas-daninhas nas diferentes estações climáticas; avaliar a dinâmica das relações entre plantas-daninhas e os cultivos; caracterizar a ecologia (riqueza e abundância) de espécies de plantas-daninhas em área de semeadura direta, por meio de análise multifractal. As amostragens foram realizadas em 1.015 pontos amostrais em malha regular de 5 × 5 m (2,38 ha), e em 1.071 pontos amostrais em malha regular de 10 × 10 m, em uma parcela experimental com semeadura direta em Campinas (São Paulo, Brasil) e Mata Roma (Maranhão, Brasil), respectivamente. No município de Campinas foi identificada predominância de *Raphanus raphanistrum* na safra de inverno, e de *Commelina* ssp. no cultivo de verão. O espectro de unicidade apresentou maior assimetria para *Raphanus raphanistrum* e *Commelina* ssp., em relação à categoria de outras plantas-daninhas. No município de Mata Roma, a planta-daninha *Commelina benghanlensis* L. foi a espécie que apresentou maior heterogeneidade medida pelo grau de multifractalidade (Δ = 0,388) e assimetria do espectro de singularidade (AI = 2,324). Assim, neste estudo foi demonstrado que as plantas-daninhas apresentam alta variabilidade espacial, com comportamento em manchas ou reboleiras e heterogeneidade em diferentes escalas, que podem ser avaliadas por meio da análise multifractal. Ademais, o presente estudo demostra a importância da análise multifractal para compreender a variabilidade espacial das plantas-daninhas, fornecendo *insights* valiosos para o manejo eficiente dessas espécies em áreas conduzidas sob sistemas de semeadura direta.

Palavras-chave: Plantas Espontâneas; Box Counting; Multifractalidade; Dimensão Generalizada; Variabilidade Espacial;

SILVA, Daniel Martins da. **Multifractal analysis of weeds in no-till system**. 2023. 79 f. Thesis (Ph.D. in Biodiversity and Biotechnology) – Federal University of Maranhão, São Luis, MA-Brazil, 2023.

ABSTRACT

Weeds show high spatial variability, exhibiting infestation behavior in patches or patches, with heterogeneity at scales that can be evaluated through multifractal analysis. Thus, the objective was to evaluate the spatial variability of weeds through multifractal analysis in direct seeding system. The specific objectives were: to investigate the dominance of weeds in different climatic seasons; evaluate the dynamics of relationships between weeds and crops; characterize the ecology (richness and abundance) of weed species in a direct seeding area, through multifractal analysis. Sampling was carried out at 1,015 sampling points in a regular 5 × 5 m mesh (2.38 ha), and at 1,071 sampling points in a regular 10 × 10 m mesh, in an experimental plot with direct seeding in Campinas (São Paulo, Brazil) and Mata Roma (Maranhão, Brazil), respectively. In the municipality of Campinas, a predominance of *Raphanus raphanistrum* was identified in the winter harvest, and of *Commelina* ssp. in summer cultivation. The uniqueness spectrum showed greater asymmetry for *Raphanus raphanistrum* and *Commelina* ssp., in relation to the category of other weeds. In the municipality of Mata Roma, the weed *Commelina benghanlensis* L. was the species that presented the greatest heterogeneity measured by the degree of multifractality (Δ = 0.388) and asymmetry of the singularity spectrum (AI = 2.324).

Thus, in this study it was demonstrated that weeds present high spatial variability, with behavior in patches or patches and heterogeneity at different scales, which can be evaluated through multifractal analysis. Furthermore, the present study demonstrates the importance of multifractal analysis to understand the spatial variability of weeds, providing valuable insights for the efficient management of these species in areas conducted under direct seeding systems.

Keywords: Spontaneous Plants; Box Counting; Multifractality; Generalized Dimension; Spatial Variability;

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1 INTRODUÇÃO

A expansão do agronegócio, o crescimento populacional e a ampliação do consumo têm gerado uma pressão por novas áreas de exploração e soluções tecnológicas para otimização dos espaços cultivados (KASTNER, *et al.*, 2012). A agricultura de precisão tem se mostrado uma solução promissora, que permite a otimização dos espaços cultivados por meio do manejo localizado (BAIO, 2001; GERHARDS *et al.*, 2002; SHIRATSUCHI *et al.*, 2003; IZQUIERDO *et al.*, 2020; JURADO-EXPÓSITO *et al.*, 2021), minimizando os custos de produção e contribuindo para o desenvolvimento sustentável.

De acordo com o Ministério da Agricultura, Pecuária e Abastecimento (MAPA), o volume de exportações do agronegócio em 23 anos, até o ano de 2021, chegou a um total de US$ 1,523 trilhões de dólares (MAPA, 2022). Em 2021, o agronegócio apresentou saldo positivo para balança comercial brasileira, de US$ 104,99 bilhões de dólares, representando assim, 42,92% das exportações brasileiras. Caso se retirasse o agronegócio das exportações, o saldo da balança comercial em 2021 seria negativo, em US$ 43,59 bilhões de dólares (MAPA, 2022). Neste sentido, a redução dos custos de produção é de vital importância para manutenção do agronegócio em crescimento.

A agricultura de precisão tem conquistado muitos adeptos, pois, permite a aplicação de dosagens diferenciadas dos herbicidas em função de características do solo e da variabilidade espacial das plantas-daninhas (METCALFE *et al.*, 2019; PÄTZOLD *et al.*, 2020; ALMEIDA e FERRÃO, 2022), sendo que, o uso de aplicações localizadas pode reduzir em 90% o volume de herbicida (GERHARDS *et al.*, 2002; SHIRATSUCHI *et al.*, 2003).

A perda de produtividade dos cultivos pode ser minimizada com o entendimento das características competitivas das plantas-daninhas por água e nutrientes (BOOTH *et al.,* 2003; BRIGHENTI e OLIVEIRA, 2011; YAMAUTI *et al.*, 2011; OLIVEIRA e BRIGHENTI, 2018; SILVA *et al.*, 2021; CASTRO *et al.*, 2021; ALMEIDA e FERRÃO, 2022), e aspectos de dispersão e reprodução que refletem espacialmente em áreas com maior ou menor concentração ou variabilidade espacial (SCHAFFRATH *et al.*, 2007; CHIBA *et al.*, 2010; SIQUEIRA *et al.*, 2016; IZQUIERDO *et al.*, 2020; JURADO-EXPÓSITO *et al.*, 2021).

A distribuição espacial das plantas-daninhas pode ser avaliada utilizando-se da análise multifractal, com intuito de entender a complexibilidade e variabilidade nas diferentes escalas de observação (SILVA *et al.*, 2022; SILVA *et al.*, 2024). A análise multifractal estima as propriedades de escalonamento de um conjunto ou sistema utilizando uma distribuição de probabilidade para quantificar a singularidade ou irregularidade de um sistema (POSADAS *et al.*, 2009; LEIVA *et al.*, 2019; SILVA; SIQUEIRA, 2020), favorecendo a compreensão das diferentes escalas de dados (EVERTSZ e MANDELBROT, 1992; BANERJEE *et al.*, 2011).

Assim, as hipóteses desse trabalho são: a) as plantas-daninhas possuem variabilidade espacial em escalas múltiplas, apresentando heterogeneidade nas escalas não descritas por métodos clássicos de análise espacial; b) riqueza e abundância das plantas-daninhas têm distribuição e associação em múltiplas escalas; c) a ferramenta de análise multifractal pode caracterizar a variabilidade espacial das plantas-daninhas em diferentes escalas.

1.1 OBJETIVOS

1.1.1 **Geral**

- Avaliar a variabilidade espacial de plantas-daninhas utilizando análise multifractal em sistema de semeadura direta.

1.1.2 **Específicos**

- Averiguar a dominância das plantas-daninhas nas diferentes estações climáticas;
- Avaliar a dinâmica das relações entre as plantas-daninhas e os cultivos;
- Caracterizar a ecologia (riqueza e abundância) entre as espécies de plantas-daninhas em área com semeadura direta por meio da análise multifractal.

2 **REVISÃO BIBLIOGRÁFICA**

2.1 PLANTAS-DANINHAS

As plantas-daninhas surgiram à medida em que o homem iniciou a produção agrícola, e começou a separar as plantas benéficas (plantas cultivadas) e maléficas (que causam prejuízo às plantas cultivadas) (BRIGHENTI e OLIVEIRA, 2011). Para MORO *et al.* (2012), as plantas-daninhas são espécies que crescem onde não são desejadas pelas pessoas, sendo contrárias aos interesses dos seres humanos. A planta desejada em um determinado local pode ser indesejada em outro e, neste local onde é indesejada, deve ser considerada como planta-daninha.

As plantas-daninhas têm características de agressividade que se sobrepõem nos cultivos e, entre elas, existem as que podem variar dependendo da espécie: maior habilidade competitiva por recursos necessários ao desenvolvimento vegetal (água, luz, nutrientes, espaço físico, CO_2), variedade na produção de propágulos, desuniformidade do processo germinativo, capacidade de germinar e emergir a grandes profundidades do solo, viabilidade dos propágulos em condições desfavoráveis, mecanismos alternativos de reprodução, facilidade de disseminação dos propágulos e crescimento e desenvolvimento inicial rápido (BOOTH *et al*., 2003; BRIGHENTI e OLIVEIRA, 2011; YAMAUTI *et al*., 2011; ALMEIDA e FERRÃO, 2022).

Um sério problema causado pelas plantas-daninhas é a redução da produtividade das plantas cultivadas. Segundo LORENZI *et al.*, (2014) a redução da produção pode chegar entre 20 e 30%. No cultivo de feijão-caupi, as plantas-daninhas reduziram o rendimento de grãos em até 46% (CORRÊA *et al.*, 2016). Além disso, as plantas-daninhas diminuem a eficiência de uso da terra e a qualidade dos produtos cultivados (BRIGHENTI e OLIVEIRA, 2011). Para minimizar os problemas causados pelas plantas-daninhas são adotadas certas práticas de manejo, as quais envolvem os métodos preventivo, cultural, físico, mecânico, biológico e químico, podendo ser empregados de forma isolda ou integrados.

O controle cultural prorporciona vantagem competitiva para a cultura perante às plantas-daninhas, por meio do uso de boas práticas de manejo de água e de uso do solo como a rotação de cultura, variação de espaçamento e uso de cobertura vegetal. No controle físico ou mecânico, empregam-se práticas para eliminação das plantas-daninhas por meio do efeito físico-mecânico, como por exemplo, monda, capina manual, roçada, inundação cobertura morta, queimada e cultivo mecânico. No controle biológico, utiliza-se o natural (pragas e doenças) para combater as plantas-daninhas. WINSTON *et al.* (2014) apresenta um catálogo sobre o controle biológico das plantas-daninhas no mundo até o ano de 2012. O controle químico é realizado por meio da utilização de produtos químicos para a eliminação das plantas-daninhas. O manejo integrado consiste na utilização de diferentes técnicas de controle de maneira combinada, sucessiva e rotativa em uma área, e em determinado tempo. O objetivo principal do manejo integrado é aproveitar os recursos disponíveis e conseguir maior eficácia no controle das plantas-daninhas (SANTOS *et al.*, 2014; OLIVEIRA e BRIGHENTI, 2018).

A resistência a herbicidas em plantas-daninhas é uma habilidade herdável para assegurar a sobrevivência e reprodução mesmo após aplicação do controle químico. Normalmente essa habilidade está associada a mudanças genéticas causadas pela seleção das plantas-daninhas, devido a sucessivas aplicações de herbicidas (PAES *et al.*, 2018). O prejuízo médio causado pela resistência dos herbicidas no Brasil, somente no cultivo da soja, está em torno de R$ 5 bilhões de reais e, levando em consideração perdas provocadas na produtividade e qualidade do grão, podendo atingir R$ 9 bilhões de reais se forem computados os gastos para o controle das plantas-daninhas (ADEGAS *et al.*, 2017).

De acordo com RICHETT (2019), o custo total com defensivos agrícolas para combate das plantas-daninhas na produção de soja Roundup Ready® (RR®), pode ser de 19,97%. Na soja modificada geneticamente com tecnologia *Bacillus thuringensis*, mais Roundup Ready® (IPRO) de 16,64%, e de 20,39% na soja convencional. No entanto, o uso de aplicações localizadas pode reduzir em 90% o volume de herbicida (GERHARDS *et al.*, 2002; SHIRATSUCHI *et al.*, 2003), porém, o uso indiscriminado de defensivos agrícolas pode provocar sérios problemas ao meio ambiente e a saúde humana (KOLLER *et al.*, 2012). Portanto, o entendimento da variabilidade das plantas-daninhas em campo, permite o manejo localizado, minimizando os custos de produção e contribuindo para o desenvolvimento sustentável.

2.2 VARIABILIDADE ESPACIAL DAS PLANTAS-DANINHAS

A variabilidade espacial de plantas-daninhas consiste em um ambiente em que há uma heterogeneidade na distribuição e densidade das espécies que compõem a flora infestante, havendo cenários em que uma área possui menor e maior concentração das mesmas. Essas áreas com elevada concentração são denominadas como manchas ou reboleiras (SCHAFFRATH *et al.*, 2007; CHIBA *et al.,* 2010; BRIGHENTI e OLIVEIRA, 2011; SIQUEIRA *et al.*, 2016; IZQUIERDO *et al.*, 2020; JURADO-EXPÓSITO *et al.*, 2021). O surgimento das reboleiras é influenciada por fatores climáticos, edáficos e ecológicos das espécies de plantas-daninhas.

Na década de 90 os estudos da variabilidade espacial das plantas-daninhas vieram a ser mais disseminados (DONALD, 1994; HEISEL *et al.*, 1996; ZANIN *et al.*, 1998). PÄTZOLD *et al.* (2020) afirmaram que a variabilidade espacial das espécies de plantas-daninhas pode ser explicada por propriedades do solo, tais como textura do solo, capacidade de água disponível e carbono orgânico do solo.

SHIRATSUCHI (2001) identificou uma correlação positiva entre o banco de sementes e a flora emergente por meio da análise geoestatística. Sendo assim, o conhecimento da variabilidade espacial do banco de sementes possibilita previsão da maior infestação das plantas-daninhas ao longo do tempo. A variabilidade espacial da planta-daninha *A. myosuroides* é pesquisada por METCALFE *et al.* (2019), que modela os efeitos das propriedades espaciais do solo na sua distribuição. BAIO (2001) elaborou um mapa de prescrição com dosagens diferentes de herbicidas, baseado na variabilidade espacial das espécies de plantas-daninhas mapeadas, correlacionando com atributos da fertilidade do solo.

O entendimento da análise espacial por meio de análise fractal e multifractal, tem sido estudado por NERY e MACHADO (2019), que analisaram a multifractalidade da variabilidade espacial pluviométrica no Estado de Minas Gerais, identificando um padrão no regime pluviométrico das regiões. Por meio da análise fractal, foi possível a compreensão de padrões na escala de pastejo, em pastagens naturais submetidas a diferentes tipos de manejos (MARTINS *et al.*, 2020). SILVA e SIQUEIRA (2020) aplicaram a multifractalidade para determinar a variabilidade espacial do índice de diversidade da fauna edáfica, em áreas com vegetação natural e em sistemas agrícolas. Contudo, a compreensão da análise multifractal para o entendimento da variabilidade espacial de plantas-daninhas ainda é pouco conhecido.

2.3 ANÁLISE MULTIFRACTAL

A racionalidade do homem na busca pela compreensão da natureza, criou a geometria euclidiana, na qual assumia que os objetos naturais possuíam uma forma regular descrita matematicamente (MANDELBROT, 1967). No entanto, é tácito que as formas da natureza não seguem um padrão regular. MANDELBROT (1975) afirma que: “as nuvens não são esferas, montanhas não são cones, os litorais não são círculos, a casca das árvores não é lisa e tampouco a luz viaja em linha reta”.

Para melhor elucidação das formas da natureza surgiu à geometria fractal, que possibilita a descrição de objetos com reentrâncias ou irregularidades (MANDELBROT, 1975). A geometria fractal possui dimensão fracionada e propriedade de auto-similaridade (as partes do objeto são pequenas cópias dele próprio) (POSADAS *et al.*, 2009). Os objetos cujas propriedades são uniformemente distribuídas são descritos corretamente pela geometria fractal, no entanto, objetos com heterogeneidade de distribuição de suas propriedades é necessário à geometria multifractal, que caracteriza a estrutura de um sistema/objeto, uma vez que a metodologia quantifica a distribuição em diferentes escalas (HENTSCHEL e PROCACCIA, 1983; CHHABRA e JENSEN, 1989; EVERTSZ e MANDELBROT, 1992; LEIVA *et al.*, 2019; SILVA; SIQUEIRA, 2020). Com isso, os objetos que podem ser representados por uma única dimensão são caracterizados como monofractal (VIDAL VAZQUÉZ *et al.*, 2013), porém, objetos que necessitam de múltiplas dimensões são caracterizados como multifractal (POSADAS *et al.*, 2009).

Na análise multifractal, os valores de dimensões são denominados dimensão generalizada (D_q), sendo que q é um momento onde o conjunto multifractal é observado (HENTSCHEL e PROCACCIA, 1983). Os intervalos de $q = 0$, $q = 1$ e $q = 2$, são os principais momentos utilizados pela dimensão generalizada, que corresponde respectivamente à dimensão de capacidade (D_0), dimensão de entropia (D_1) e dimensão de correlação (D_2) (HENTSCHEL e PROCACCIA, 1983; POSADAS *et al.*, 2009; LEIVA *et al.,* 2019; SILVA e SIQUEIRA, 2020). A dimensão de capacidade (D_0) descreve uma visão global do sistema (LEIVA *et al.,* 2019), permitindo averiguar como as escalas estão preenchidas por valores de medidas. A dimensão D_1 se relaciona à informação da entropia e quantifica o grau de desordem do sistema. Assim, valores de D_1 próximos de 2, indicam sistemas com distribuição uniforme (POSADAS *et al.*, 2009), enquanto que, valores de D_1 próximos de 1, representam subconjuntos, com irregularidades na distribuição dos valores de medidas (POSADAS *et al.*, 2009; LEIVA *et al.,* 2019; SILVA e SIQUEIRA, 2020). Enquanto a dimensão D_2, calcula a correlação das medidas contidas em uma caixa de tamanho ε (HENTSCHEL e PROCACCIA, 1983).

As dimensões generalizadas em um sistema monofractal são iguais ($D_0 = D_1 = D_2$), no entanto, para sistemas multifractais os valores devem seguir a relação $D_0 > D_1 > D_2$ (CHHABRA e JENSEN, 1989; BANERJEE *et al.*, 2011; VIDAL-VÁZQUEZ *et al.*, 2013; SIQUEIRA *et al.*, 2018; LEIVA *et al.,* 2019; SILVA e SIQUEIRA, 2020). Para descrever a análise multifractal, podem ser utilizados diferentes métodos, como: o método direto (CHHABRA e JENSEN, 1989), o método do momento (HALSEY *et al.*, 1986) e *Box*

Counting (EVERTSZ e MANDELBROT, 1992), que permite analisar padrões de um suporte geométrico, que é dividido em sucessivos segmentos (POSADAS *et al*., 2009).

O método *box counting* realiza a segmentação do suporte geométrico (δ), sucessivas vezes tendendo ao infinito, permitindo assim, descrever o número de caixas para cada intervalo do suporte geométrico (N = 2, 3, 4, 5, 6 ...) (EVERTSZ e MANDELBROT, 1992). O entendimento da variabilidade espacial de plantas-daninhas, por meio da análise multifractal, ainda é pouco explorado, entretanto, a técnica já é aplicada para o entendimento da variabilidade de escala de diferentes propriedades de solo (VIDAL-VÁZQUEZ *et al.*, 2013; DAFONTE *et al.*, 2015; SIQUEIRA *et al.*, 2018; LEIVA *et al.*, 2019) e de planta-daninha (SILVA *et al.*, 2022; SILVA *et al.*, 2024).

O método multifractal empregado por VIDAL-VÁZQUEZ *et al.* (2013) analisam e comparam os padrões de escala de heterogeneidade estrutural das propriedades do solo ao longo de dois transeptos, em Campinas (São Paulo, Brasil), utilizando o formalismo multifractal. DAFONTE *et al.* (2015), analisam os padrões de escala e heterogeneidade de atributos químicos do solo, em Corunha, na Espanha. SIQUEIRA *et al.* (2018) identificam padrões de heterogeneidade de atributos químicos do solo em cultivos com a monocultura de cana-de-açúcar (*Saccharum officinarum* sp.), no Estado de Pernambuco (Brasil). Sendo que, LEIVA *et al.* (2019), no cultivo da cana-de-açúcar no município de Coelho Neto (Maranhão, Brasil), determinou a multifractalidade de perfis verticais da resistência do solo à penetração em diferentes unidades de relevo. A análise multifractal empregada considera a propriedade de escala de cada perfil e tipificada o espectro de singularidade e de Rènyi, estimados por meio do método do momento.

A heterogeneidade das plantas-daninhas em uma área de semeadura direta foi avaliada por SILVA *et al.* (2022) por meio da análise multifractal. A pesquisa foi realizada em uma parcela experimental de 2,38 hectares no município de Campinas (São Paulo, Brasil), a princípio cultivada com triticale e, posteriormente, com soja, identificou a predominância sazonal de *Raphanus raphanistrum* no inverno e *Commelina* ssp. no verão. Os diferentes graus de heterogeneidade apresentados pela análise multifractal evidenciaram os processos de dispersão e colonização do ambiente pelas diferentes plantas-daninhas avaliadas. As espécies *Raphanus raphanistrum* e *Commelina* ssp. demonstraram domínio de baixos valores, enquanto outras plantas-daninhas (OW) exibiram maior variabilidade.

SILVA *et al.* (2024) avaliaram propriedades de escala de plantas-daninhas em sistema de semeadura direta na Pré-Amazônia, utilizando análise multifractal. Na amostragem foi realizada em área de cultivo de soja em Mata Roma (Maranhão, Brasil), foram observados diferentes graus de multifractalidade, destacando-se *Euphorbia hirta* e *Turnera subulata*. A assimetria no espectro de singularidade dessas espécies sugere predominância de valores elevados de medidas.

Esses estudos empregam o formalismo multifractal para analisar e comparar os padrões de escala e heterogeneidade das propriedades do solo e plantas-daninhas em diversas regiões. Assim, contribuem para uma melhor compreensão dos atributos químicos do solo, resistência do solo à penetração e da dinâmica de dispersão e colonização das plantas-daninhas. Portanto, a geometria fractal e a análise multifractal oferecem ferramentas e métodos que permitem descrever e compreender as formas complexas e irregulares encontradas na natureza. Essas abordagens são particularmente úteis na análise de sistemas e objetos com distribuições heterogêneas de propriedades em diferentes escalas.

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CAPÍTULO I - MULTISCALE PROPERTIES OF WEEDS IN NO-TILL SYSTEM

Advances Weed Science

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Highlights

- Weeds have high spatial variability that can be assessed through multifractal analysis.
- The analyzed weeds showed scale heterogeneity with different degrees of multifractality.
- *Raphanus raphanistrum* (L.) and *Commelina* ssp. (L.) exhibited domains of low measurement values on the scales.

Abstract:

Background: Weeds have high spatial variability and show clustering behavior, with heterogeneity in scales that can be evaluated through multifractal analysis.

Objective: The objective of this study was to evaluate the spatial variability of weeds using multifractal analysis in a no-till area.

Methods: Sampling was conducted at 1,015 sampling points in an experimental plot with a regular grid of 5 × 5 m (2.38 ha) with no tillage. The area was cultivated with triticale (*Triticum secale*), and in the summer of 2011, the area was cultivated with soybean (*Glycine max*). Data were analyzed using descriptive statistics and multifractal analysis using the box-counting method to determine the scaling properties of the variables.

Results: The predominance of *Raphanus raphanistrum* was identified in the winter crop and *Commelina* ssp. during the summer. The singularity spectrum showed greater asymmetry for *Raphanus raphanistrum* and *Commelina* ssp. in relation to the category of other weeds (OW). The degree of multifractality varied throughout the study period, showing the ecological patterns of the studied species. Scale heterogeneity was revealed, with different degrees of multifractality that evidenced the processes of dispersion and colonization of the environment by the different weed species evaluated.

Conclusions The species *Raphanus raphanistrum* and *Commelina* ssp. showed domains of low measurement values, and OW was the most heterogeneous.

Keywords: Spontaneous Plants; Multifractality; Generalized Dimension; Singularity Spectrum; Spatial Variability

Conflict of Interest

The authors have no conflicts of interest to declare regarding the research.

1. Introduction

Weeds compete with agricultural crops for water and nutrients (Booth et al., 2003; Brighenti, Oliveira, 2011; Yamauti et al., 2011), and have high spatial (Schaffrath et al., 2007; Jurado-Expósito et al., 2021) and temporal variability (Chiba et al., 2010; Izquierdo et al., 2020).

In the field, weeds have dispersal and reproduction characteristics that result in zones with greater or lesser concentrations, and are often shown assembling in groups (Schaffrath et al., 2007; Chiba et al., 2010; Brighenti, Oliveira, 2011; Siqueira et al., 2016; Izquierdo et al., 2020; Jurado-Expósito et al., 2021). Therefore, understanding the scale of weed variability in the field allows for localized management, minimized production costs, and sustainable development.

Spatial variability can be assessed using different methodologies, including geostatistical and multifractal analyses. In geostatistical analysis, data are modeled to ascertain the spatial dependence between samples (Vieira, 2000), whereas multifractal analysis evaluates data to understand the complexity and variability in different observation scales (Evertsz, Mandelbrot, 1992).

Multifractal analysis has been used to characterize spatial variability and describe irregularities and structures with a variety of scales (Vidal-Vázquez et al., 2013). According to Kohmoto (1988) and Posadas et al. (2009), multifractal analysis estimates the scaling properties of a set or system using a probability distribution to quantify the uniqueness or irregularity of that system. When the irregularity is equal on all scales, at least statistically, a multifractal system exists (Evertsz, Mandelbrot, 1992). The structure of fractal objects or sets is characterized by an infinite number of dimensions (Hentschel, Procaccia, 1983), which allows for the description of the singularity spectrum (Chhabra, Jensen, 1989). Thus, multifractal analysis describes the structure of a system/object, since the methodology quantifies the spatial distribution of values on the scales (Leiva et al., 2019; Silva, Siqueira, 2020; Siqueira et al., 2022), thereby favoring the understanding of the heterogeneity of the data (Banerjee et al., 2011), which is not characterized by other methods.

The use of multifractal analysis to understand the spatial variability of weeds is still poorly understood; however, this technique has previously been used to determine the variability of soil and plant scales. Vidal-Vázquez et al. (2013), Dafonte et al. (2015), and Siqueira et al. (2018) analyzed the scale patterns and heterogeneity of soil chemical attributes. Posadas et al. (2009) characterized the flow of water in soils through multifractality, while Leiva et al. (2019) determined the multifractality of vertical profiles of soil resistance to penetration in different relief units. Silva and Siqueira (2020) and Siqueira et al. (2022) determined the multifractality of invertebrate soil fauna.

Thus, the hypothesis of this study is that weeds have spatial variability in multiple scales and present heterogeneity in scales that are not described by classical methods of spatial analysis. Thus, the objective of this study was to evaluate the spatial variability of weeds using multifractal analysis in a no-till area in Campinas, São Paulo, Brazil.

2. Material and Methods

2.1. Description of the experimental area

The study area was 2.38 ha (140 × 170 m; Figure 1a), and carried out in the Campinas, São Paulo, Brazil (22º53´ S and 47º04´ W, and altitude average of 600 m), with soil classified as dystrophic red latosol (Santos et al., 2018). The region's climate transitions between Cwa (temperate humid climate with dry winters and hot summers) and Cfa (subtropical climate), and the average temperature of the warmest month is greater than or equal to 22º C and the coldest month is less than 18º C. The annual precipitation is 1,462 mm.

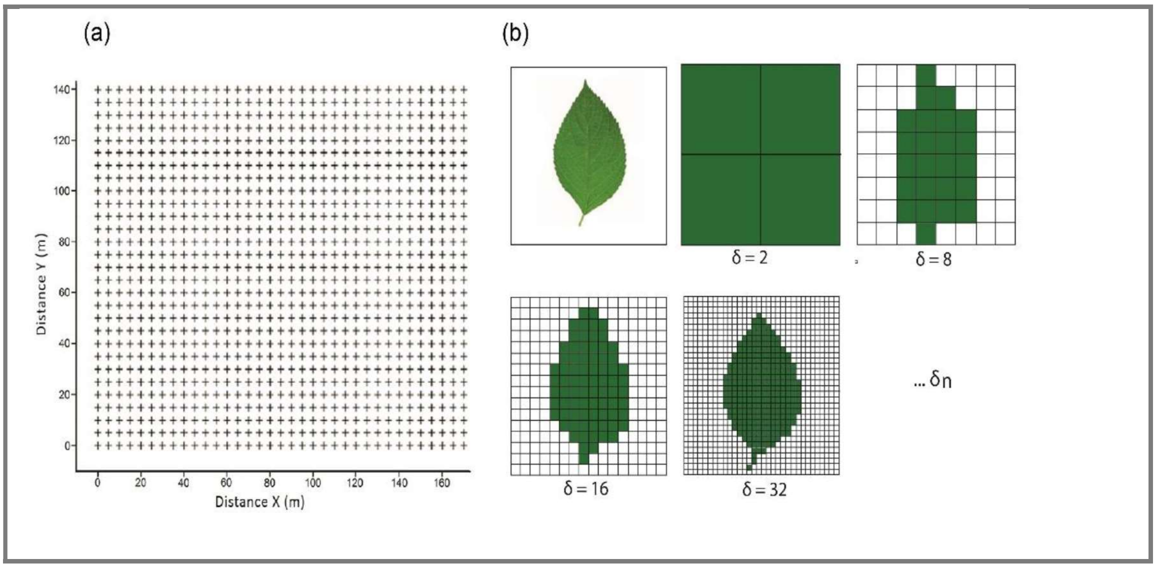

Figure 1 - (a) Sampling scheme (5 × 5 m) of weeds in Campinas, (São Paulo, Brazil), (b) Description of the box counting method for successive segments

Since 1985, the study area was managed by direct seeding with cover crops in the winter and grain in the summer between October and November, and the harvest occurred between February and March. Chemical management for weed control was performed with the application of 1.5 L ha^{-1} of 2.4D + 1 L ha^{-1} of glyphosate in the period prior to the cultivation of winter and summer crops.

2.2. Sampling

In the study area, 1,015 sampling points were demarcated in a regular grid of 5 × 5 m (Figure 1a) for weed sampling on the following dates: 07/16/2010, 08/19/2010, 10/22/2010, 01/26/2011, and 02/17/2011. At the time of sampling, the study area was cultivated with triticale (*Triticum secale* Wittmack) as a winter crop and soybean [*Glycine max* (L.) Merrill] as a summer crop. Weed sampling was performed by casting a circle with a diameter of 1.126 m (1 m^2) randomly and counting and identifying the number of weeds present at each sampling point. Weeds were identified following the procedures described by Lorenzi (2014), and a predominance of *Raphanus raphanistrum* (L.) in winter and *Commelina* ssp. (L.) in summer was observed, as well as other weeds (OW) that showed lower expression levels, including: *Bidens pilosa* L., *Amaranthus deflexus* L., *Ipomoea grandifolia* (Dammer) O'Donell, *Acanthospermum australe* (Loerfl.) Kuntze, *Digitaria insularis* (L.) Fedde, *Euphorbia heterophylla* L. and *Parthenium hysterophorus* L.

2.3. Descriptive statistics and multifractal analysis

Data were analyzed using descriptive statistics to determine mean ($\overline{x}$), variance, standard deviation, coefficient of variation (%), asymmetry, kurtosis, and D (maximum deviation from the normal distribution using the Kolmogorov–Smirnov test, with an error probability of 0.01). The coefficient of variation (CV) was classified according to Warrick and Nielsen (1980) as low (CV < 12%), medium (12% < CV < 60%), or high (CV > 60%).

The multifractal analysis was performed using the software NASS - Non-linear Analysis Scaling System (Posadas and Ferraz, 2019), using the box counting method, which allows for pattern analysis of a geometric support, which is divided into successive segments. Figure 1b illustrates the procedures for segmenting the geometric support (δ), and allowing the description of the number of boxes for each interval (N = 2, 3, 4, 5, 6, 7, ...). Thus, the method considers an infinite number of successive segments for the geometric support ($n \rightarrow \infty$: Evertsz, Mandelbrot, 1992). Therefore, it is possible to estimate the scaling properties of a fractal set or system to determine the contents of the boxes using a probability distribution, which quantifies the contents and then describes the singularity (α) (Kohmoto, 1988). The probability (P) of heterogeneous systems (Equation 1) is then used to estimate the scale properties for a set of spatial data (Posadas et al., 2009).

$$P_i(\varepsilon) \sim \varepsilon^{\alpha_i} \quad (1)$$

where α_i is the Lipschitz-Hölder exponent, also known as the singularity force that can vary in the interval ($\alpha_{-\infty}$, $\alpha_{+\infty}$), and ε is the scale. Multifractal sets are characterized on the basis of the generalized dimensions (D) of the point of order q in a D_q distribution (Hentschel, Procaccia, 1983), defined by Equation 2:

$$D_q = \lim_{\varepsilon \to 0} \left(\frac{1}{q-1} \frac{\log \mu(q,\varepsilon)}{\log(\varepsilon)} \right) \quad (2)$$

where μ(q,ε) corresponds to the partition function defined by Equation 3, and by replacing q with 0, 1, and 2 in Equation 2, we obtain the capacity dimension (D_0, Equation 4), information dimension (D_1, Equation 5), and correlation dimension (D_2, Equation 6), respectively.

$$\mu(q,\varepsilon) = \sum_{i=1}^{N(\varepsilon)} P_i^q(\varepsilon) \quad (3)$$

$$D_0 = \lim_{\varepsilon \to 0} \frac{\log(N(\varepsilon))}{\log(\varepsilon)} \quad (4)$$

$$D_1 = \lim_{\varepsilon \to 0} \frac{\sum_{i=1}^{N(\varepsilon)} \mu_i(\varepsilon) \log(\mu_i(\varepsilon))}{\log(\varepsilon)} \quad (5)$$

$$D_2 = \lim_{\varepsilon \to 0} \frac{\log(C(\varepsilon))}{\log(\varepsilon)} \quad (6)$$

In multifractal systems, the spectra of dimensions or singularity spectra (q) are defined by Equations 7 and 8 (Chhabra, Jensen, 1989).

$$f(q) = \lim_{\varepsilon \to \infty} \frac{1}{\log(\varepsilon)} \sum_{i=1}^{N(\varepsilon)} \mu_i(q,\varepsilon) \log[\mu_i(q,\varepsilon)] \quad (7)$$

$$\alpha(q) = \lim_{\varepsilon \to \infty} \frac{1}{\log(\varepsilon)} \sum_{i=1}^{N(\varepsilon)} \mu_i(q,\varepsilon) \log[P_i(\varepsilon)] \quad (8)$$

Asymmetry (AI) and degree of multifractality (Δ) of the data were determined according to Halsey et al. (1986), considering the values of α and D_q (equation 9 and 10).

$$AI = \frac{\alpha_0 - \alpha_3}{\alpha_{-5} - \alpha_0} \quad (9)$$

$$\Delta = D_{-\infty} - D_{+\infty} \quad (10)$$

AI is the asymmetry of the system, α_0 is the value of f(α) in the range 0, α_3 is the value of f(α) in the interval q = 3, α_{-5} is the value of f(α) in the interval q = -5; and D is the generalized dimension at points q = 3 and q = -5.

3. Results and Discussion

3.1. Statistical analysis

The weeds with the highest density in the study area (Table 1) were *R. raphanistrum* on 10/22/2010 ($\bar{x}$ = 8.85 plants per m2) and *Commelina* ssp. on 01/26/2011 ($\bar{x}$= 9.31 plants per m^2). Schappert et al. (2018) described an abundance of *R. raphanistrum* of 3.0 plants per m^2 in their study of weeds, whereas Castro et al. (2021) discovered that for weeds in agricultural production areas of southern Brazil, *Commelina benghalensis* had an average density of 15.2 plants per m^2 in a no-tillage system.

Table 1 - Descriptive statistics for the number of weeds in the years 2010 and 2011

Sampling	Weeds	$\bar{x}$	Variance	SD	CV (%)	Skew	Kurtosis	D
07/16/2010	*R. raphanistrum*	7.91	40.14	6.34	80	1.78	4.37	0.10 Ln
	OW	3.79	32.56	5.71	151	5.13	32.21	0.11 Ln
08/19/2010	*R. raphanistrum*	5.84	51.68	7.19	123	3.77	18.18	0.10 Ln
	OW	2.38	4.38	2.09	88	2.31	5.68	0.21 Ln
10/22/2010	*R. raphanistrum*	8.85	105.27	10.26	116	4.05	26.38	0.10 Ln
	OW	41.96	2473.34	49.73	119	3.08	13.97	0.09 Ln
01/26/2011	*Commelina ssp.*	9.31	96.47	9.82	105	2.93	12.28	0.10 Ln
	OW	4.63	111.99	10.58	229	8.03	74.05	0.16 Ln
02/17/2011	*Commelina ssp.*	6.90	37.33	6.11	89	1.95	5.27	0.10 Ln
	OW	4.01	35.25	5.94	148	3.05	9.36	0.15 Ln

R. raphanistrum - Raphanus raphanistrum L.; *Commelina ssp. - Commelina ssp.* L.; OW – Other weeds; $\bar{x}$ - mean; SD - Standard deviation; CV - Coefficient of variation (%); D - Kolmogorov-Smirnov test of normality ($p < 0.01$).

In the present study, OW were identified with lower occurrence winter and summer crops: B. *pilosa, A. deflexus, I. grandifolia, A. australe, D. insularis, E. heterophylla*, and *P. hysterophorus* distributed in the area in clusters and with regular occurrence, with the smallest number of OW described on 08/19/2010 and the largest on 10/22/2010. According to Booth et al. (2003) and Brighenti and Oliveira (2011), weeds have a high capacity for reproducing viable seeds and special adaptations for dissemination, which justifies their occurrence in clusters, as described by Schaffrath et al. (2007), Chiba et al. (2010), and Jurado-Expósito et al. (2021). Weeds are also associated with the cropping system adopted in the field (Izquierdo et al., 2020).

The lowest and highest coefficients of variation (%, Table 1) were described for *R. raphanistrum* on 07/16/2010 (CV = 80%) and 08/19/2010 (CV = 123%), respectively. The highest CV value (%) for OW was reported on 01/26/2011 (CV = 229%), and the lowest was found for the data from 08/19/2010 (CV = 88%). According to the classification by Warrick and Nielsen (1980), the CV percentages in this study were classified as high (CV > 60%). Chiba et al. (2010) reported that high CV values for weeds reveal that their distribution in the field is heterogeneous. Thus, the occurrence of a lognormal frequency distribution (Ln) for the data was expected, as verified by the Kolmogorov-Smirnov test (D – Table 1) and the asymmetry and kurtosis values.

3.2. Multifractal analysis

The multifractality of the weed data in the study period was determined considering points of order q (-5 < q < 3), evaluated on a scale of 0.1, and the multifractal parameters are shown in Table 2. In monofractal systems, the dimensions are equal ($D_0 = D_1 = D_2$) (Dafonte et al., 2015); however, for multifractal systems the dimensions must follow the relationship $D_0 > D_1 > D_2$ (Chhabra, Jensen, 1989; Banerjee et al., 2011; Vidal-Vázquez et al., 2013; Siqueira et al., 2018; Leiva et al., 2019; Silva, Siqueira, 2020); therefore, data on weed species (*R. raphanistrum, Commelina* ssp. and OW) follow the relationship $D_0 > D_1 > D_2$ (Table 2), indicating a multifractal behavior.

Table 2 - Multifractal parameters for weeds identified in the study area

Sampling	Weeds	q_-	q_+	α_{-5}	α_3	α_0	AI	Δ	D_0	D_1	D_2
07/16/2010	*R. raphanistrum*	-5	3	2.297	1.726	2.019	1.050	0.383	1.944	1.866	1.806
	OW	-5	3	2.320	1.658	1.935	0.715	0.497	1.801	1.708	1.676
08/19/2010	*R. raphanistrum*	-5	3	2.369	1.673	2.029	1.049	0.507	1.896	1.774	1.716
	OW	-5	3	1.936	1.650	1.689	0.155	0.151	1.677	1.666	1.656
10/22/2010	*R. raphanistrum*	-5	3	2.402	1.676	2.089	1.321	0.535	1.941	1.797	1.727
	OW	-5	3	2.493	1.724	2.131	1.122	0.576	1.972	1.831	1.770
01/26/2011	*Commelina ssp.*	-5	3	2.338	1.710	2.039	1.097	0.434	1.947	1.851	1.783
	OW	-5	3	2.026	1.687	1.774	0.342	0.219	1.739	1.711	1.696
02/17/2011	*Commelina ssp.*	-5	3	2.278	1.716	2.010	1.095	0.394	1.923	1.837	1.779
	OW	-5	3	2.158	1.690	1.806	0.328	0.318	1.748	1.709	1.695

R. raphanistrum - *Raphanus raphanistrum* L.; *Commelina ssp.* - *Commelina ssp.* L.; OW - Other weeds; α_{-5}, α_3, α_0, are the spectra of singularities for the moments q = -5, q = 3 and q = 0; AI - Asymmetry; Δ - degree of multifractality; D_0 – Capacity dimension; D_1 – Information dimension; D_2 – Correlation dimension.

The lowest and highest values of D_0 (Table 2) were described for OW on 10/22/2010 (D_0 = 1.972) and 08/19/2010 (D_0 = 1.677). The capacity dimension (D_0) describes a global view of the system (Leiva et al., 2019; Siqueira et al., 2022), allowing us to verify how the scales are filled by the measurement values. Variations in D_0 values for *R. raphanistrum, Commelina* ssp., and OW on the sampling dates showed that the scales were filled with measurement values, indicating that the difference in D_0 values for the species under study reflects their ecology (Booth et al., 2003; Brighenti, Oliveira, 2011), mainly with regard to the aggregated distribution (Cheam, Code, 1995; Schaffrath et al., 2007; Chiba et al., 2010; Siqueira et al., 2016; Pereira et al., 2018; Izquierdo et al., 2020; Sousa et al., 2020; Jurado-Expósito et al., 2021). The D_1 dimension is related to the entropy information and quantifies the degree of disorder in the system. Thus, D_1 values close to 2 indicate systems with uniform distribution (Posadas et al., 2009), while D_1 values close to 1 represent subsets, with irregularities in the distribution of measurement values (Posadas et al., 2009; Leiva et al., 2019; Silva, Siqueira, 2020; Siqueira et al., 2022). Here, the values of D_1 varied between 1.866 and 1.666 (Table 2), indicating a tendency toward uniformity in the distribution of the scales in the study area. The D_2 dimension calculates the correlation of the measurements contained in a box of size ε (Hentschel, Procaccia, 1983); thus, it is possible to state that for each of the evaluated dates, there was a correlation in the spatial distribution of the measurements.

The highest values of the Hölder exponent (α_0) were identified for OW on 10/22/2010 (2.131), *R. raphanistrum* on 10/22/2010 (2.089), and *Commelina* ssp. on 01/26/2011 (2.131). The Hölder exponent (α_0) characterizes the multifractal scale of the system (Silva, Siqueira, 2020); therefore, there is an increasing trend over the period studied for *R. raphanistrum* and *Commelina* ssp. However, for the OW, the pattern was not repeated, with the lowest value described for OW on 08/19/2020 (α_0 = 1.650) and the highest for 10/22/2020 (α_0 = 2.131).
The lowest and highest asymmetry values (AI, Table 2) were described for OW on 08/19/2010 (AI = 0.155) and *R. raphanistrum* on 10/22/2010 (AI = 1.321), respectively. Asymmetry (AI) is an indicator of the heterogeneity of the system (Silva, Siqueira, 2020), which can assume positive or negative values. Positive asymmetry indicates an association in scales related to low measurement values, and negative asymmetry indicates an association in high measurement value scales (Vidal-Vázquez et al., 2013). The asymmetry values found indicate greater heterogeneity for *R. raphanistrum* than for *Commelina* ssp. (Table 2). The asymmetry of OW (Table 2) varied throughout the study period, without showing any increasing or decreasing pattern; however, the data demonstrated the dominance of *R. raphanistrum* and

Commelina ssp. over the OW occurring in the study area, indicating ecological processes of dominance and distribution of weeds in the scales.

The highest and lowest degrees of multifractality ($\Delta = D_{-5} - D_3$; Table 2) were described for OW on 10/22/2010 ($\Delta = 0.576$) and 08/19/2010 ($\Delta = 0.151$), respectively. The degree of multifractality identifies systems with greater or lesser heterogeneity (Vidal-Vázquez et al., 2013; Dafonte et al., 2015; Siqueira et al., 2018). The multifractality of OW tended to increase during the winter (triticale) and summer (soybean), indicating an increase in complexity during the crop cycles. *R. raphanistrum* showed an increase in heterogeneity throughout the crop cycle of triticale, while *Commelina* ssp. lost complexity throughout the soybean cycle. The increase in complexity of *R. raphanistrum* and loss of complexity for *Commelina* ssp. are justified by the environmental interactions of these weed species. For *R. raphanistrum,* competition for resources in the environment escalates with the increase in the triticale canopy (Yamauti et al., 2011), thereby increasing its complexity, as evaluated by the degree of multifractality (Δ). However, the population dynamics of *Commelina* ssp. diminished as the soybean crop developed, thereby losing complexity (Δ).

The generalized dimension graph for weeds in the study area with positive ($q = 0$ to $q = 3$) and negative ($q = 0$ to $q = -5$) points are shown in Figure 2. According to Posadas et al. (2009) and Leiva et al. (2019), the generalized dimension graph describes the spatial variability of the value measurements, characterizing the heterogeneity of the system. The generalized dimension graph (Figure 2a) shows that D_q is a decreasing function of q, shaped like a sigma curve, indicating that there is variability in the low and high measurement values of the studied weeds. For the OW category (Figure 2b), it appears that for the negative points ($q = 0$ to $q = -5$), there is a greater degree of heterogeneity in the scales compared to the positive points ($q = 0$ to $q = 3$), demonstrating that the dynamics of weeds in this category have high variability in the study period.

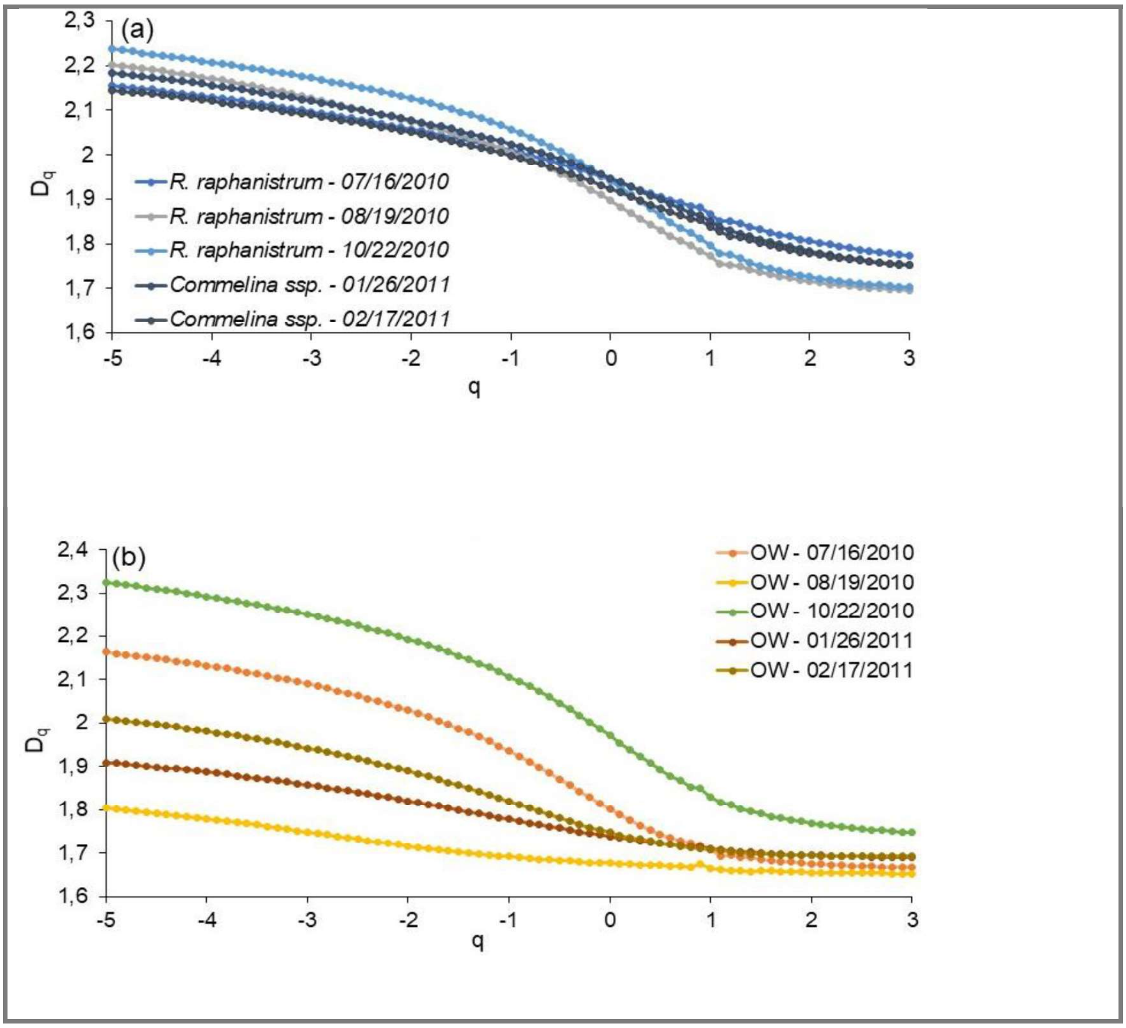

Figure 2 - Generalized dimension graph (D_q) for the number of weeds identified in triticale and soybean crops under no-tillage: (a) *R. raphanistrum* and *Commelina* ssp. and (b) OW – Other weeds

The singularity spectrum plots for *R. raphanistrum* and *Commelina* ssp. (Figure 3a) exhibit descending and concave parabolas, and according to Dafonte et al. (2015) and Silva and Siqueira (2020), this format confirms the multifractality of the data. The singularity spectra for *R. raphanistrum* and *Commelina* ssp. show positive asymmetry (right branch), indicating that in the study area and on the different sampling dates, low values of measurements occurred. Information regarding the heterogeneity and complexity of *R. raphanistrum* and *Commelina* ssp. has potential for weed management, because our results describe greater heterogeneity and are associated with low measurement values, indicating that these scales can be used to determine the degree of infestation. It is noteworthy that the singularity spectra for *R. raphanistrum* and *Commelina* ssp. (Figure 3a) show similarity in the distribution behavior of the scales in the branches, with the greatest difference being described for *R. raphanistrum* on 10/22/2010 (AI = 1.321; Table 2) at the end of the triticale crop cycle.

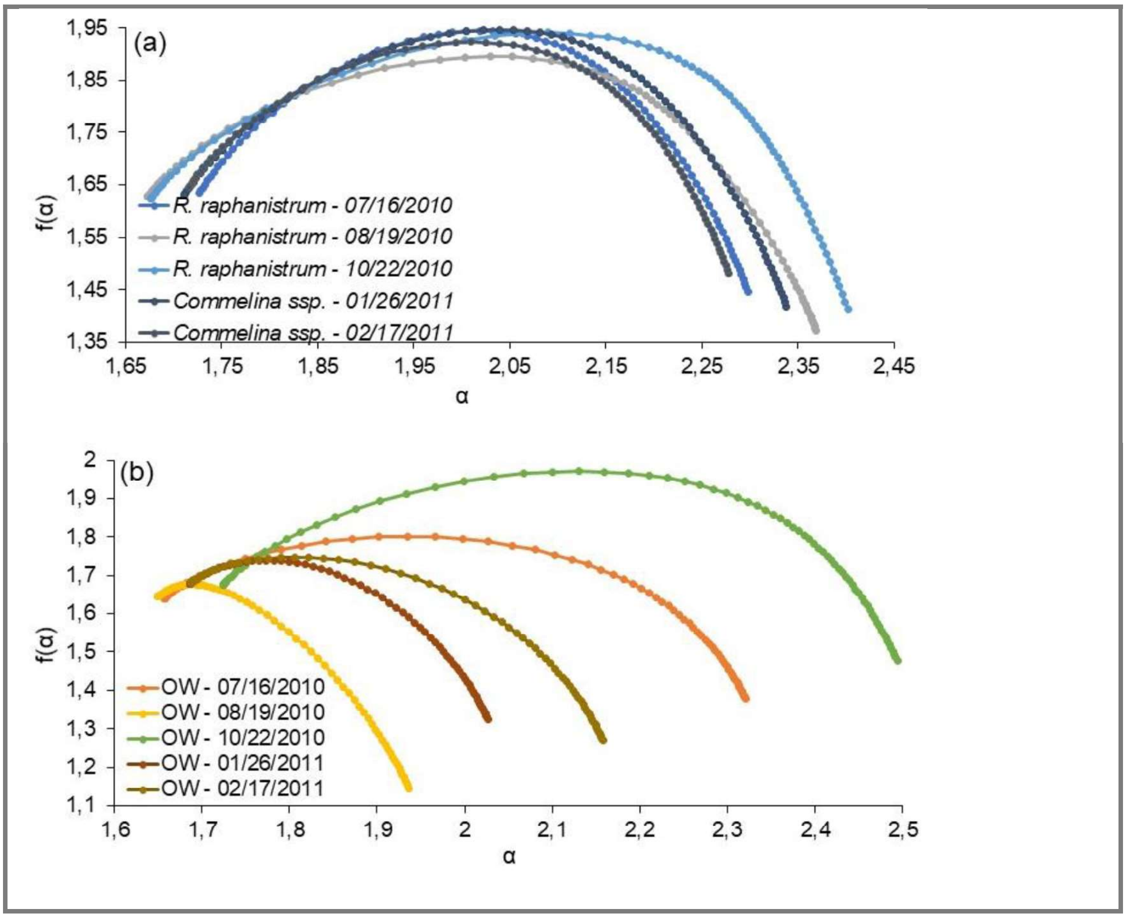

Figure 3 - Singularity spectrum for the number of weeds identified in triticale and soybean crops under no-tillage: (a) *R. raphanistrum* and *Commelina* ssp.; (b) OW – Other weeds

The singularity spectrum for OW (Figure 3b) is asymmetrical to the right, indicating the domain of low measurement values in the study area, but with a lower degree of multifractality (Δ) and asymmetry, when compared to *R. raphanistrum* and *Commelina* ssp. (Table 2 and Figure 2). We emphasize that the multifractality of OW in winter and in summer expressed by the singularity spectrum indicates that, during the study period, OW presented high variability in the distribution of scales, corroborating the complex of interactions that this category of study plants represents (*Bidens pilosa* L., *Amaranthus deflexus* L., *Ipomoea grandifolia* (Dammer) O'Donell, *Acanthospermum australe* (Loerfl.) Kuntze, *Digitaria insularis* (L.) Fedde, *Euphorbia heterophylla* L., and *Parthenium hysterophorus* L.). The differences in the singularity spectrum for OW in the study period describe the dynamics of the dispersal and colonization processes of the environment (Booth et al., 2003; Brighenti, Oliveira, 2011) by the species grouped in this category, the dominance of *R. raphanistrum* and *Commelina* ssp., and the competition with triticale and soybean crops for environmental resources.

3.3. Ecology and weed management

The prevalence and dominance of *R. raphanistrum* (L.) throughout winter crops and of *Commelina* ssp. (L.) in summer crops is a response to characteristics of species ecology. According to Lorenzi (2014) and Pereira et al. (2018), the species *R. raphanistrum* (L.) has a high capacity for the production of viable seeds and is a common spontaneous plant for winter crops. Cheam and Code (1995) report that the occurrence of *R. raphanistrum* (L.), even if at low populational densities, can compromise the productivity of winter crops. As for *Commelina* ssp. (L.), Brighenti and Oliveira (2011) describe the species as being resistant to chemical management with glyphosate, and, according to Sousa et al. (2020), its control is hindered due to the low efficiency of mechanical methods since its rapid reproduction occurs vegetatively or through seeds. Hence, during the present research period, the species with the most significant expression presented different reproductive and occupational strategies, resulting in high spatial variability and variability scale.

Consequently, multifractal analysis has a significant potential for describing species ecology in the field of agricultural production. The D_0, D_1 and D_2 (Table 2) values are indicators of richness, entropy, and evenness, respectively, allowing one to understand the diversity, complexity, and heterogeneity dynamics of weed ecology within the study area, and should follow the $D_0 > D_1 > D_2$ relation (Chhabra, Jensen, 1989; Banerjee et al., 2011; Vidal-Vázquez et al., 2013; Siqueira et al., 2018; Leiva et al. 2019; Silva, Siqueira, 2020; Siqueira et al., 2022). Thus, it is essential we understand that the focus of multifractal analysis is the description of variable complexity, which will lead to the understanding of weed ecology dynamics.

The singularity spectrum (Figures 3 and 4), in its turn, describes weed dynamics and complexity in the research area in terms of spatial and scale variability. Based on the singularity spectrum, it is possible to attain the characterization of asymmetry (AI), multifractality (Δ) and variability scale distribution. Negative or positive asymmetry (AI) allows the description of possible dominance of high or low measurement values, respectively. With this, weed management strategies can be identified on a scale never considered before. The complexity of the system, or the complexity of the ecological dynamics of weed species, is assessed by the degree of multifractality (Δ). Systems with a greater complexity express heterogeneous weed species dynamics, while homogenous systems represent low species diversity and weed phenological homogeneity in the field. Therefore, multifractal analysis is a promising tool for weed management, the development of new control indicators, and localized input application for the practice of precision agriculture.

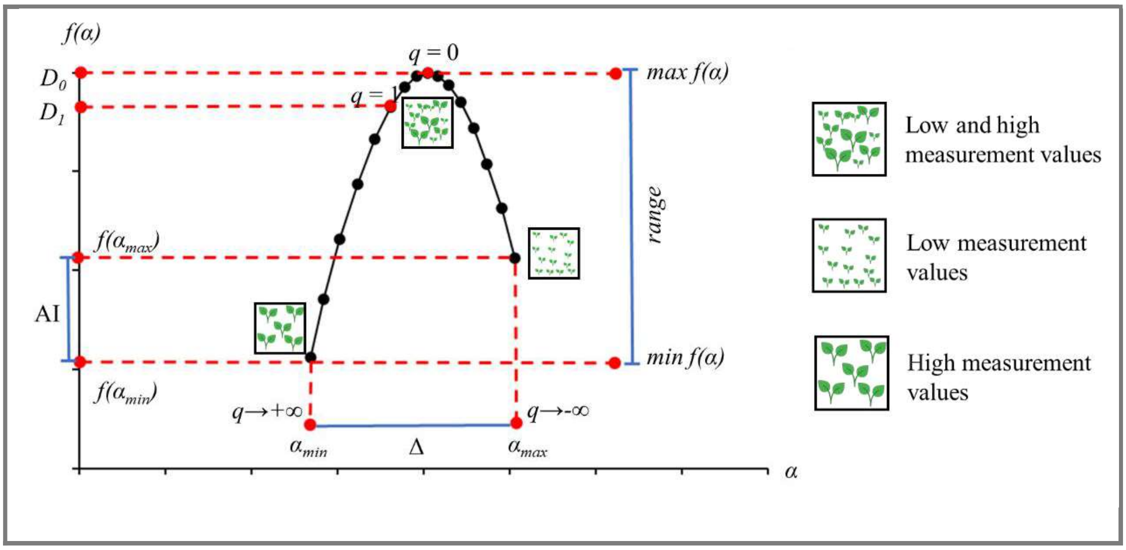

Figure 4 - Interpretation of the multifractal singularity spectrum

Within the area of new research perspectives, we point out the use of multifractal analysis for localized identification of weed species in embedded systems, considering species leaf architecture at different stages of vegetative development. The use of the multifractal methodology should also be highly considered for weed management with the use of drone images, where the ecological relations among species can be understood, as well as the dominance in variability scales for commercial crops.

4. Conclusions

Raphanus raphanistrum L. was the dominant weed in winter cultivation, whereas *Commelina* ssp. L. was dominant in summer cultivation. Different degrees of multifractality were observed for the weeds, and the OW category was the most heterogeneous. During the study period, *Raphanus raphanistrum* L. and *Commelina* ssp. L. showed less asymmetry of the branches of the singularity spectrum than OW, indicating the dominance of low measurement values. Therefore, multifractal analysis can be a promising tool for understanding the spatial dynamics of weed distribution.

Author's contributions

All authors read and agreed to the published version of the manuscript. GSM: Conceptualization of the manuscript and development of the methodology, data collection and curation, project administration, supervision. DMS and GSM: data analysis, writing, review and editing. DMS, JFM, RNB, and GSM: data interpretation, writing the original draft of the manuscript.

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CAPÍTULO II - MULTIFRACTAL ANALYSIS OF WEEDS IN A NO-TILLAGE SYSTEM IN THE PRE-AMAZON REGION

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HIGHLIGHTS:

Weeds present varying spatial variability scales.

Euphorbia hirta *L. exhibited high density and abundance.*

Commelina benghalensis *L. exhibited the greatest heterogeneity among the evaluated weeds*

ABSTRACT: Weeds have several mechanisms of dispersal and reproduction, resulting high spatial variability. The objective of this study was to assess the scale and spatial heterogeneity of weeds using multifractal analysis in a no-tillage system in the Pre-Amazon region. Sampling was conducted in a commercial soybean (*Glycine max*) production plot in the Mata Roma, Maranhão, Brazil, comprising 1,071 points marked on a 10 × 10 m grid. Data were analyzed using descriptive statistics and multifractal analysis through the box-counting method. Weeds showed varying degrees of multifractality, resulting in different scales and spatial heterogeneity in the study area. *Euphorbia hirta* and *Turnera subulata* exhibited asymmetry of branches to the left in the singularity spectrum, indicating dominance of high measurement values.

Keywords: Spontaneous plants; Degree of multifractality; Generalized dimension; Singularity spectrum.

Análise Multifractal das plantas-daninhas em sistema de semeadura direta na região Pré-Amazônia

RESUMO: As plantas-daninhas possuem diversos mecanismos de dispersão e reprodução descrevendo elevada variabilidade espacial. O objetivo deste estudo foi avaliar a heterogeneidade de escala e espacial de plantas-daninhas utilizando análise multifractal em sistema de semeadura direta na região Pré-Amazônia. A amostragem foi realizada em uma parcela de produção comercial cultivada com soja (*Glycine max*). Na área de estudo foram demarcados 1.071 pontos, em malha regular de 10 × 10 m, no município de Mata Roma (Maranhão, Brasil). Os dados foram analisados por meio da estatística descritiva e análise multifractal empregando o método box-counting. As plantas-daninhas apresentaram diferentes graus de multifractalidade, descrevendo maior ou menor heterogeneidade de escala e espacial na área de estudo. *Euphorbia hirta* e *Turnera subulata* apresentaram assimetria dos ramos do espectro de singularidade para a esquerda, indicando domínio de valores elevados de medidas.

Palavras-Chave: Plantas espontâneas; Grau de multifractalidade; Dimensão generalizada; Espectro de singularidade.

INTRODUCTION

Weeds in agricultural production areas present high spatial variability (Chiba et al., 2010; Siqueira et al. 2016; Silva et al., 2022), and can compromise crop yields when not properly managed (Gazziero et al., 2015; Siqueira et al., 2016; Caetano et al., 2018; Castro et al., 2021; Silva et al., 2021; Silva et al., 2022; Osunleti et al., 2022).

Spatial variability of weeds has been described through different methods. Chiba et al. (2010) and Siqueira et al. (2016) analyzed the spatial variability of weeds using geostatistical tools, whereas Silva et al. (2022) evaluated scale properties of weeds using multifractal analysis. Multifractal analysis characterizes the structure of a system or object, allowing for the evaluation of the distribution of measurement values at different scales, thus describing the spatial variability (Hentschel & Procaccia, 1983; Halsey et al., 1986; Evertsz & Mandelbrot, 1992; Posadas et al., 2009). Therefore, it enables the assessment of the heterogeneity of a system (Vidal-Vázquez et al., 2013; Bertol et al., 2017; Santos et al., 2019; Leiva et al., 2019; Silva & Siqueira, 2020, Leiva et al., 2021; Siqueira & Silva, 2022; Siqueira et al., 2022; Silva et al., 2022). According to Dafonte et al. (2015), it is possible to determine whether the structure of a system is monofractal or multifractal.

Therefore, the hypothesis in this work is that the spatial distribution of weeds constitutes multifractal systems. The objective of this study was to evaluate the scale and spatial heterogeneity of weeds using multifractal analysis in a no-tillage system in the Pre-Amazon region.

MATERIALS AND METHODS

The study was conducted in a 10-hectare area (Figure 1) in Mata Roma, state of Maranhão, Brazil (3°42'26.56"S, 43°11'19.56'W, and average altitude of 130 m). The soil of the area was classified as a Latossolo Vermelho-Amarelo típico by the Brazilian Soil Classification System (Santos et al., 2018), which corresponds to a Typic Hapludox (United States, 2022). The region presents an Aw climate, according to the Koppen classification, with two well-defined seasons: a dry season from June to November and a rainy season from December to May, with an annual rainfall depth of 1,835 mm, temperatures ranging from 23 to 36 °C, and a mean relative air humidity is 80%. The study area has been managed with crop rotation since 2007, with soybean [*Glycine max* (L.) Merrill] and maize (*Zea mays* L.) crops under no tillage system, with subsoiling up to a depth of 0.32 m, when necessary, every five years.

Figure 2. Map of Brazil with the location of the study area in Mata Roma, Maranhão, Brazil

Sampling was conducted when the area was cultivated with soybeans, sown on December 23, 2016. Weeds were sampled on January 12, 2017, at 1,071 points distributed in a 10×10 m grid (Figure 2), considering weeds within circular plots with a useful area of approximately 1

m^2 (1.126 m diameter). Weeds were counted and identified following the procedures described by Gazziero et al. (2015). A total of 21,217 individuals were identified: *Euphorbia hirta* L. (10,021), *Spigelia anthelmia* L. (4,399), *Spermacoce verticillata* L. (2,024), *Cenchrus echinatus* L. (1,968), *Turnera subulata* Sm. (1,586), *Commelina benghalensis* L. (925), *Sida rhombifolia* L. (147), *Desmodium tortuosum* (Sw.) DC. (83), and *Scoparia dulcis* L. (64). *Sida rhombifolia* L., *Desmodium tortuosum* (Sw.) DC., and *Scoparia dulcis* L. were grouped into a category called Other Weeds (OW) due to their lower expression in the study area.

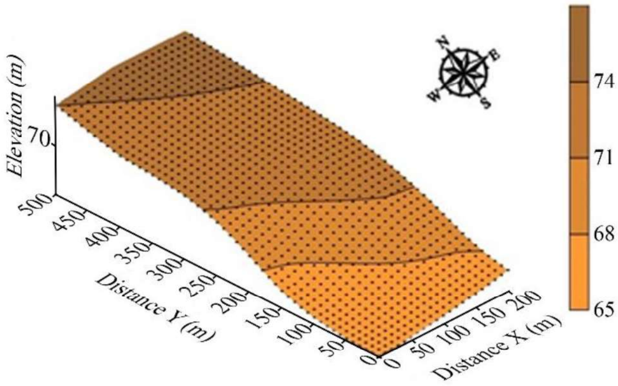

Figure 2. Altimetric map and sampling arrangement (10×10 m) for weed sampling in an area under no-tillage system in Mata Roma, Maranhão, Brazil

The ecology among species was evaluated according to Küchler et al. (1976), considering: Density = total number of individuals per species / total number of sampling points in the area (plants m^{-2}); Relative Density = species density × 100 / sum of densities of all specimens (%); Frequency = number of sampling points containing the species / total number of sampling points obtained in the area; Relative Frequency = species frequency × 100 / sum of frequencies of all specimens (%); Abundance = total number of individuals per species / total number of sampling points containing the species; Relative abundance = species abundance × 100 / sum of abundances of all specimens (%); and Importance Value Index (IVI) = relative density +

relative frequency + relative abundance (%). Richness was determined by the total number of taxonomic groups identified at each sampling point.

Data of the weed species *E. hirta*, *S anthelmia*, *S. verticillata*, *C. echinatus*, *T. subulata*, *C. benghalensis* and OW were subjected to descriptive statistical analysis to obtain the main statistical moments: mean ($\bar{x}$), variance, standard deviation, coefficient of variation (CV%), asymmetry, kurtosis, and D (maximum deviation from the normal distribution using the Kolmogorov-Sminorv test, with $p \geq 0.01$). The coefficient of variation was classified as low ($CV < 12\%$), moderate ($12\% < CV < 60\%$), or high ($CV > 60\%$), according to Warrick & Nielsen (1980).

The multifractal analysis was conducted using the Non-linear Analysis Scaling System (NASS) software (Oliveira et al., 2022), and the box-counting method, which allows for the subdivision of the geometric support (δ) into grids of size (L) and successive moments (N = 2, 3, 4, 5, 6, 7 ...), thus the segments are evaluated successively tending to infinity, $n \rightarrow \infty$ (Evertsz & Mandelbrot, 1992).

In heterogeneous systems, the contents of the grids can be quantified following the scale properties (Eq. 1 - Table 1), using a probability distribution (*P*), which enables the estimation of the scale properties (ε) in the i_{th} region or spatial location (Posadas et al., 2009); thus, the Hölder exponent (α_i) can vary in the interval ($\alpha_{-\infty}, \alpha_{+\infty}$). The partition function $\mu(q, e)$ (Eq. 2) of order q is confirmed based on the scale properties, where $N(\varepsilon)$ is the number of segments with size ε and the statistical moments q are defined by $-\infty< q <\infty$. Furthermore, the partition function is dimensioned as $\varepsilon^{\tau(q)}$ (Eq. 3), where the exponent $\tau(q)$ is the moment correlation exponent of order q, also known as the mass function (Halsey et al., 1986). In this sense, multifractal sets are characterized through the generalized dimension (*D* - Equation 4) for moments of order q in a Dq distribution (Hentschel & Procaccia, 1983); when q is replaced by 0, 1, and 2, it is possible to determine the dimensions of capacity (Eq. 5), information (Eq. 6) and correlation (Eq. 7), respectively.

Table2. Equations used in the multifractal analysis process

Partition function	$P_i(\varepsilon) \sim \varepsilon^{\alpha_i}$	(1)
	$\mu(q,\varepsilon) = \sum_{i=1}^{N(\varepsilon)} P_i^q(\varepsilon)$	(2)
	$\mu(q,\varepsilon) \sim \varepsilon^{\tau(q)}$	(3)
Generalized dimension	$D_q = \lim_{\varepsilon\to 0}\left(\frac{1}{q-1}\frac{\log \sum_{i=1}^{N(\varepsilon)} P_i^q(\varepsilon)}{\log(\varepsilon)}\right)$	(4)
	$D_0 = \lim_{\varepsilon\to 0}\frac{\log(N(\varepsilon))}{\log(\varepsilon)}$	(5)
	$D_1 = \lim_{\varepsilon\to 0}\frac{\sum_{i=1}^{N(\varepsilon)} \mu_i(\varepsilon)\log(\mu_i(\varepsilon))}{\log(\varepsilon)}$	(6)
	$D_2 = \lim_{\varepsilon\to 0}\frac{\log(C(\varepsilon))}{\log(\varepsilon)}$	(7)
Spectrum of singularities	$f(q) = \lim_{\varepsilon\to\infty}\frac{1}{\log(\varepsilon)}\sum_{i=1}^{N(\varepsilon)} \mu_i(q,\varepsilon)\log[\mu_i(q,\varepsilon)]$	(8)
	$\alpha(q) = \lim_{\varepsilon\to\infty}\frac{1}{\log(\varepsilon)}\sum_{i=1}^{N(\varepsilon)} \mu_i(q,\varepsilon)\log[P_i(\varepsilon)]$	(9)
Degree of multifractality (Δ) and asymmetry (AI)	$\Delta = D_{-5} - D_5$	(10)
	$AI = \frac{\alpha_0 - \alpha_5}{\alpha_{-5} - \alpha_0}$	(11)

P – Probability distribution; *i* – Spatial location; *ε* – Scale; *α* – Hölder exponent; *μ(q, e)* – Partition function; *N(ε)* – number of segments with size *ε*; *q* – Statistical moment; *τ(q)* – Correlation exponent at the moment of order q; D –Generalized dimension; *C(ε)* – Correlation function; *f* – Singularity function; *α* – Uniqueness spectrum; Δ – Degree of multifractality; *AI* – Asymmetry;

The dimension spectra or singularity spectra (*q*) are defined by Equations 8 and 9 (Chhabra & Jensen, 1989), which specify that the scale properties of the partition function reflect the contribution of individual segments. The degree of multifractality (*Δ* - Equation 10) and asymmetry (*AI* - Equation 11) of the data were determined considering the values of D_q and α where: *D* is the generalized dimension at times q = -5 and q = 5; *AI* is the asymmetry of the system; *α0* is the value of *f(α)* in interval 0; α_5 is the value of *f(α)* in the interval q = 5; and α_{-5} is the value of *f(α)* in the interval q = -5 (Halsey et al., 1986).

RESULT AND DISCUSSION

The diversity parameters presented in Table 2 are indicators used to characterize the ecology among species. Density, frequency, and abundance express the participation of different species, the spatial distribution of each specimen, and concentration of species in the study area, respectively (Küchler et al., 1976; Siqueira et al., 2016; Caetano et al., 2018; Castro et al., 2021). The importance value index (IVI) is intended to characterize which species have a greatest influence within the weed community (Caetano et al., 2018), thus, the higher the IVI (Table 2), the higher the positive species rate at the sampling points.

Table 2. Ecological variables for weed species in Mata Roma, Maranhão, Brazil

Variable	D	RD	F	RF	A	RA	IVI
Cenchrus echinatus L.	1.84	9.28	0.97	17.08	1.89	7.65	34.00
Commelina benghalensis L.	0.86	4.36	0.81	14.23	1.06	4.31	22.90
Desmodium tortuosum (Sw.) DC.	0.08	0.39	0.05	0.80	1.69	6.87	8.06
Euphorbia hirta L.	9.36	47.23	1	17.54	9.36	37.92	102.69
Scoparia dulcis L.	0.06	0.30	0.06	1.05	1	4.05	5.40
Sida rhombifolia L.	0.14	0.69	0.10	1.69	1.43	5.78	8.16
Spermacoce verticillata L.	1.89	9.54	1	17.54	1.89	7.66	34.74
Spigelia anthelmia L.	4.11	20.73	0.91	15.95	4.52	18.31	54.99
*Turnera subulata S*m.	1.48	7.48	0.81	14.13	1.84	7.45	29.05
Total	19.81	100	5.70	100	24.67	100	300

D – Density (plants m^{-2}); RD – Relative density (%); F – Frequency; RF – Relative frequency (%); A – Abundance; RA – Relative abundance (%); IVI - Importance value index (%).

The weed species with the highest density (D) and relative density (RD - Table 2) were *E. hirta* (D = 9.36 plants m^{-2} and RD = 47.23%), *S. anthelmia* (D = 4.11 plants m^{-2} and RD = 20.73%), *S. verticillata* (D = 1.89 plants m^{-2} and RD = 9.54%), *C. echinatus* (D = 1.84 plants m^{-2} and RD = 9.28%), and *T. subulata* (D = 1.48 plants m^{-2} and RD = 7.48%). The highest D and RD of the species *E. hirta* reflect its ecological characteristics. According to Gazziero et al. (2015), *E. hirta* is an annual, latex-bearing, semi-prostrate, pigmented plant with rapid seed reproduction; furthermore, plants of the genus *Euphorbia* are among the most worrying in soybean crops, as they have reproduction and dispersal strategies that make their management difficult. Similarly, Caetano et al. (2018) and Castro et al. (2021) evaluated weeds in areas of the Brazilian Cerrado biome with soybean crops under no-tillage system and reported predominance of *E. hirta*.

Osunleti et al. (2022) evaluated weed control methods and reported *S. anthelmia* as the species with the highest density and relative density in the treatments evaluated, mainly due to its high degree of tolerance to oxyfluorfen at a rate of 0.36 kg ha^{-1}. The other weed species found in the present work had less expressiveness, which is consistent with the results of Chiba et al. (2010), Gazziero et al. (2015), Siqueira et al. (2016), Caetano et al. (2018), Castro et al. (2021), Silva et al. (2021), and Silva et al. (2022).

The species with the highest frequency were *E. hirta* (F = 1) and *S. verticillata* (F = 1); frequency close to one denotes uniformity in the distribution of weeds in the study area; *E. hirta* and *S. verticillata* were found in all sampling points. The species with the highest abundance was *E. hirta* (A = 9.36 – Table 2), with a high concentration of weed plants, resulting in a higher importance value index (IVI = 102.69). According to Freitas et al. (2021) *Euphorbiacea* is a family of species with short cycles, tiny inflorescences, and a high potential for seed production. This explains the high incidence of *E. hirta* in the study area, as described by the ecological parameters (Table 2).

The three species with the lowest IVI [*S. rhombifolia* (8.16%), *D. tortuosum* (8.06%), and *S. dulcis* (5.40%)] were grouped into the category Other Weeds (OW). According to Carvalho & Carvalho (2009) and Gazziero et al. (2015), species in the OW category have later germination relative to the soybean cycle, explaining the occurrence of lower IVI for these species.

The statistical parameters of weeds in the study area are shown in Table 3. The species *E. hirta* had the highest mean number of individuals ($\overline{x}$ = 9.36 plants per m^2), followed by *S. anthelmia* (4.52 plants per m^2) and OW ($\overline{x}$ = 2.85 plants per m^2). These are similar results to those found in other studies. Samuel & Rastogi (2022) evaluated the ecology of *E. hirta* and found 4.11 plants per m^2. Silva et al. (2022) evaluated multiscale properties of weed plants and found a mean of 11.35 plants per m^2 for the OW category, involving five species: *Bidens pilosa* L., *Amaranthus deflexus* L., *Ipomoea grandifolia* (Dammer) O'Donell, *Acanthospermum australe* (Loerfl.) Kuntze, *Digitaria insularis* (L.) Fedde, *Euphorbia heterophylla* L., and *Parthenium hysterophorus* L.

Table 3. Descriptive statistics for the number of weed plants

Weeds	$\overline{x}$	Variance	SD	CV (%)	Skew	Kurtosis	D-KS
Cenchrus echinatus L.	1.89	0.21	0.46	24.00	-0.44	1.32	0.05 Ln
Commelina benghalensis L.	1.06	0.06	0.25	23.00	3.55	10.66	0.06 Ln
Euphorbia hirta L.	9.36	20.03	4.48	48.00	1.64	6.43	0.05 Ln
Spermacoce verticillata L.	1.89	0.20	0.45	24.00	-0.45	1.40	0.05 Ln
Spigelia anthelmia L.	4.52	4.28	2.07	46.00	0.49	-0.50	0.05 Ln
*Turnera subulata S*m.	1.84	1.08	1.04	57.00	1.66	5.13	0.06 Ln
OW	2.85	5.38	2.32	81.00	3.76	15.65	0.16 Ln

OW – Other weeds [*Sida rhombifolia* L., *Desmodium tortuosum* (Sw.) DC, and *Scoparia dulcis* L.]; $\overline{x}$ - mean (plants per m^2); SD - Standard deviation; CV - Coefficient of variation (%); D-KS - Maximum deviation from the normal distribution using the Kolmogorov-Smirnov test at $p \geq 0.01$.

The coefficients of variation (CV%; Table 3) of the evaluated weeds were classified as moderate (12 % < CV < 60 %), according to Warrick & Nielsen (1980); except for the OW category (CV = 81%) which presented a high CV (> 60%). The OW category encompassed three weed species [*D. tortuosum*, *S. dulcis*, and *S. rhombifolia*], with high heterogeneity in the study area and cluster distribution (Chiba et al., 2010; Siqueira et al., 2016; Castro et al., 2021; Silva et al., 2022), as well as distinct ecological processes (Gazziero et al., 2015).

The weeds had a lognormal frequency distribution (Table 3), according to the Kolmogorov-Smirnov normality test (D-KS, $p < 0.01$), which is consistent with the median to high CV and the asymmetry and kurtosis values.

Table 4 presents the results of the multifractal analysis for moments of order q in the interval from q = -5 to q = +5. In multifractal systems, the capacity dimension (D_0), information dimension (D_1), and correlation dimension (D_2) follow the pattern: $D_0 > D_1 > D_2$ (Posadas et al., 2009; Vidal-Vázquez et al., 2013; Dafonte et al., 2015; Bertol et al., 2017; Leiva et al., 2019; Silva & Siqueira, 2020; Leiva et al., 2021; Siqueira et al., 2022; Silva et al., 2022). Therefore, the variables represent multifractal systems, as they present the pattern $D_0 > D_1 > D_2$, except for OW, which represents a monofractal system. According to Dafonte et al. (2015), a monofractal system present the following dimension pattern: $D_0 \approx D_1 \approx D_2$. OW represents a monofractal system due to the characteristics of the species in this class, as there are three species that occur in the study area with independent spatial patterns, resulting in high variability (CV = 81.00%) and comprising a chaotic system.

Table 4. Multifractal parameters of the attributes of the study area images.

Weeds	q_-	q_+	Δ	D_0	D_1	D_2	α_{-5}	α_5	α_0	AI
Cenchrus echinatus L.	-5	5	0.255	1.995	1.986	1.980	2.532	1.953	2.007	0.102
Commelina benghalensis L.	-5	5	0.388	1.995	1.913	1.818	2.227	1.657	2.055	2.324
Euphorbia hirta L.	-5	5	0.124	1.995	1.984	1.971	2.118	1.845	2.005	1.401

Spermacoce verticillata L.	-5	5	0.191	1.995	1.986	1.981	2.319	1.955	2.006	0.164
Spigelia anthelmia L.	-5	5	0.094	1.995	1.988	1.980	2.151	1.935	2.002	0.448
Turnera subulata Sm.	-5	5	0.219	1.995	1.967	1.942	2.167	1.805	2.024	1.529
Richness	-5	5	0.071	1.995	1.992	1.988	2.163	1.969	1.998	0.172
Abundance	-5	5	0.086	1.995	1.988	1.980	2.122	1.907	2.001	0.780
OW					monofractal					

Richness – Species richness per point; Abundance – Abundance of weeds per point; OW - Other weeds; Δ – degree of multifractality; D_0 – Capacity dimension; D_1 – Information dimension; D_2 – Correlation dimension; α_{-5}, α_5, α_0 are the singularity spectra for the moments q = -5, q = 5 and q = 0 respectively; AI – Asymmetry.

The capacity dimension (D_0 = 1.995) remained constant for all evaluated weed species, with values close to 2, indicating that almost all boxes/scales are filled with measurement values, as described by Posadas et al. (2009). The information dimension (D_1) measures the degree of heterogeneity in the system (Siqueira et al., 2022), and values close to 2 represent a relatively uniform distribution of measurement values across scales, whereas values close to 1 represent sets that have concentrated irregularities (Leiva et al., 2019; Silva et al., 2022). The highest and lowest D_1 values (Table 4) were found for Richness (D_1 = 1.992) and for *C. benghalensis* (D_1 = 1.913); despite the numerical difference in D_1, in both cases, the values are close to 2, indicating uniformly distributed systems. Mathematically, the values of correlation dimension (D_2 - Table 4) are associated with the correlation function (Hentschel & Procaccia, 1983) and describe how measurements are distributed in boxes/scales. The results showed that D_2 values ranged from 1.818 (*C. benghalensis*) to 1.988 (Richness), indicating low irregularity in the data series.

The degree of multifractality (Δ – Table 4) describes systems with higher or lower heterogeneity (Vidal-Vázquez et al., 2013; Siqueira & Silva, 2022). The highest degree of multifractality was found for *C. benghalensis* (Δ = 0.388 – Table 4), indicating that this species occurs in the study area at a low density (D = 0.86 – Table 2). In the present study, the multifractality values (Δ) reflected heterogeneous systems with greater or lesser complexity for the biological systems under study (Silva et al., 2022).

The species with the highest occurrence in the study area showed a lower degree of multifractality (Δ) due to the homogenous distribution of these species in the experimental plot. Silva et al. (2022) evaluated the multifractality of weeds and reported that the degree of multifractality represents the complexity of the ecological dynamics of weeds, reinforcing the findings of the present study.

The diversity indices Richness and Abundance showed the lowest degree of multifractality (Δ = 0.071 and Δ = 0.086, respectively), as expected, since these indices represent measures with certain uniformity across boxes.

C. benghalensis had the highest Hölder exponent (α_0 = 2.055) and asymmetry (AI = 2.324) values. Thus, this species system had the highest multifractality/heterogeneity. Overall, the Hölder exponent (α_0) values found for the other weed species varied slightly from one species to another, indicating that the colonization process by weeds in the study area is structured, however, with different spatial variability scales among species. Contrastingly, asymmetry (AI) values showed a high variation in the study area, with the highest value found for *C. benghalensis* (AI = 2.324) and the lowest for *C. echinatus* (AI = 0.102). The presence of positive asymmetry (AI) indicates greater variability at scales corresponding to low measurement values (Siqueira et al., 2022; Silva et al., 2022), denoting a more frequent occurrence of low measurement values throughout the study area.

The generalized dimension (Figure 3A) at moment *q* (D_q) is a decreasing function with a sigma curve shape. The graph for *C. benghalensis* demonstrates that at times $q = 0$ to $q = 5$ there is a difference from the other weeds, showing higher heterogeneity, which is consistent with the result found for the degree of multifractality (Table 4 - Δ = 0.388). Richness had the lowest variation for both positive ($q = 0$ to $q = 5$) and negative ($q = 0$ to $q = -5$) moments, denoting greater system homogeneity and lower multifractality, as shown by the degree of multifractality (Table 4 - Δ = 0.071).

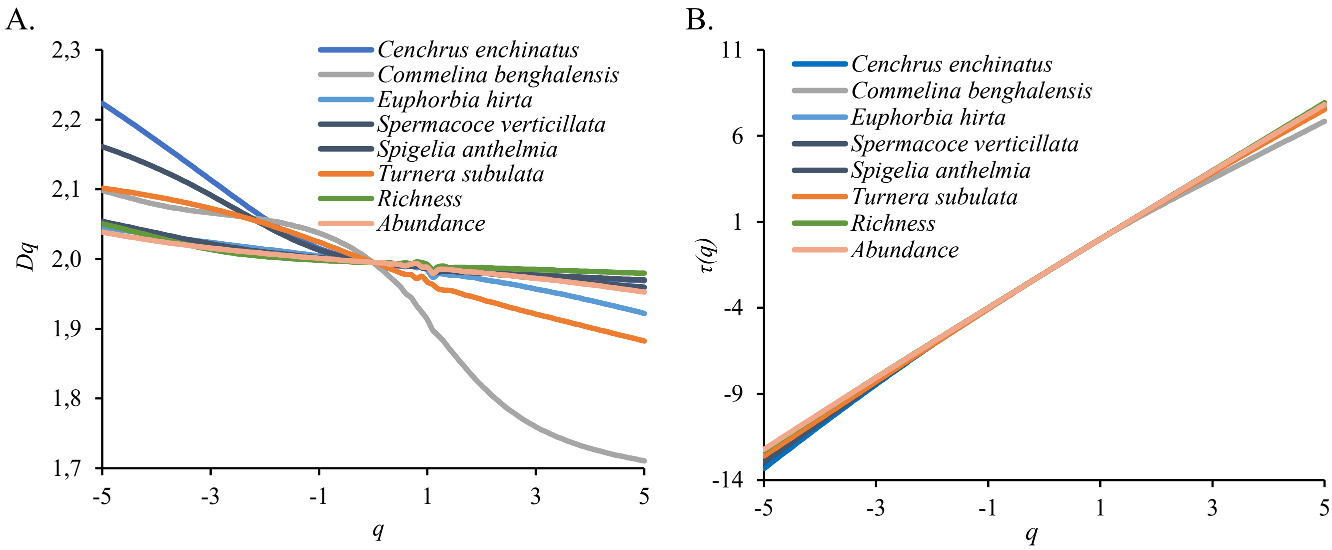

Figure 3. Generalized dimension graph (D_q *vs q* - A) and mass exponent graph (*τ(q) vs q* - B). *q* = statistical moment; D_q = generalized dimension for moments of order *q*; *τ(q)* = correlation exponent at the moment of order *q*

The mass exponent or Rényi graph (Figure 3B) shows multifractal behavior for all evaluated variables. According to Santos et al. (2019), linear graphs do not represent multifractal patterns, whereas nonlinear functions correspond to multifractal systems, i.e., mass exponent graphs do not exhibit linear functions, but they present a certain curvature.

Weed plants (*C. enchinatus*, *S. verticillate,* and *S. anthelmia*) and ecological variables (Richness and Abundance) (Figure 4) have a multifractal spectrum with asymmetry of the branches to the right, indicating dominance of low measurement values. The uniqueness spectrum for *C. benghalensis*, *E. hirta,* and *T. subulata* exhibits asymmetry to the left, indicating dominance of high measurement values. Information on the domain of weed values allows for effective rate of production inputs, avoiding waste, thus preserving the environment.

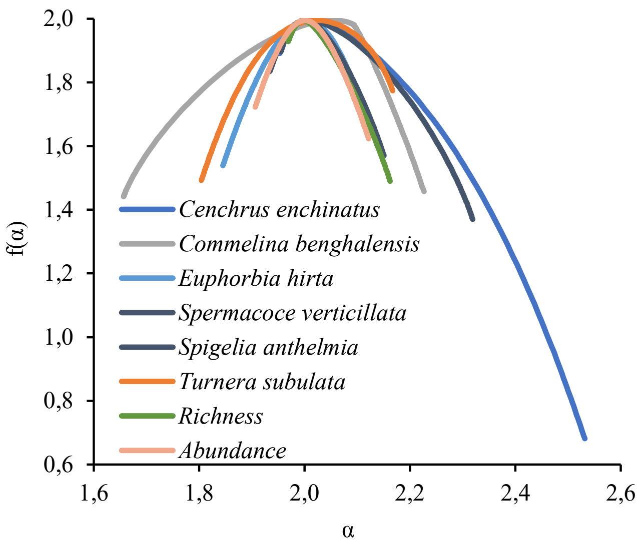

Figure 4. Singularity spectrum for weeds identified in soybean crops under no-tillage system (*α* - uniqueness spectrum; *f(α)* - singularity function for moments of order *α*;)

The results found in this study are consistent with findings from other studies, such as those by Vidal-Vázquez et al. (2013), Silva & Siqueira (2020), and Silva et al. (2022), who evaluated the uniqueness spectrum and described the predominance of high and low values related to the left and right branches of the spectrum, respectively. The singularity spectrum (Figure 4) displays descending and concave parabolas (Bertol et al., 2017) confirming the multifractal behavior of the data (Dafonte et al., 2015).

The results showed that the promising use of multifractal analysis for studying weed plants, as it was possible to identify multifractal patterns related to ecological processes of the different species under study, including seed dispersal ability, dormancy period, and reproduction with a high disseminule production capacity (Gazziero et al., 2015; Freitas et al., 2021). The generalized dimension graph provides information on the spatial variability of measurement values, describing greater and lesser heterogeneity in the system (Posadas et al., 2009; Leiva et al., 2019). The singularity spectrum graph proved to be effective in evaluating the domain of measurement values (low or high), highlighting spatial distribution patterns that would not be characterized by other spatial analysis methods. The identification of spatial distribution patterns of weeds on a multifractal scale enables the development of increasingly precise management strategies.

CONCLUSIONS

1. Weeds exhibited varying degrees of multifractality (*C. benghalensis* - Δ = 0.388, *C. enchinatus* - Δ = 0.255, *T. subulata* - Δ = 0.219, *S. verticillata* - Δ = 0.191*, E. hirta* - Δ = 0.124, and *S. anthelmia* - Δ = 0.094), resulting in greater or lesser scales and spatial heterogeneity in the study area.
2. *Euphorbia hirta* and *Turnera subulata* presented asymmetry of branches to the left in the singularity spectrum, indicating dominance of high measurement values.

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CONCLUSÕES

A análise multifractal apresentou-se como uma ferramenta promissora para o entendimento da dinâmica espacial da distribuição de plantas-daninhas, pois, a partir da análise multifractal em área com semeadura direta nos municípios de Campinas (São Paulo, Brasil) e Mata Roma (Maranhão, Brasil), foi possível a identificação de áreas com maior e menor homogoniedade de plantas-daninhas, permitindo assim, o controle com acuracidade.

Desse modo, no município de Campinas (São Paulo, Brasil) foi identificada predominância de *Raphanus raphanistrum* na safra da espécie *Commelina* ssp. L. foi dominante no cultivo de verão, enquanto a *Raphanus raphanistrum* L., foi à planta-daninha dominante no cultivo de inverno. A categoria OW apresenta maior heterogeneidade com uma tendência de aumento durante o ciclo das culturas de inverno (triticale) e verão (soja), indicando aumento da complexidade ao longo dos ciclos dos cultivos. A caracterização das plantas-daninhas por meio da análise multifractal, possibilitou a compreensão da dinâmica das relações entre as plantas-daninhas e o cultivo, refletindo assim, o comportamento populacional das mesmas na área.

Nesse sentido, as plantas-daninhas estudadas no município de Mata Roma (Maranhão, Brasil), evidenciaram diferentes graus de multifractalidade, descrevendo maior (*Commelina benghanlensis* L.) e menor heterogeneidade (*Richness*) de escala espacial. Os parâmetros ecológicos (*Richness* e Abundância) possuem espectro multifractal com assimetria dos ramos para a direita, indicando domínio de valores de medidas baixos.

Portanto, o presente estudo se justifica, pois, fornece informações sobre a variabilidade de plantas-daninhas em diferentes escalas, até então ignoradas pelos métodos tradicionais, colaborando para determinar zonas com domínio de valores elevados e baixos de medidas. Assim, permite-se o controle e aplicação localizada de insumos, contribuindo para desenvolvimento sustentável. As pesquisas desenvolvidas foram analisadas para os biomas Mata Atlântica (Campinas, São Paulo), sob os cultivos de soja e triticale, e para o bioma Cerrado (Mata Roma, Maranhão) cultivada com soja, que podem subsidiar futuros estudos em outros biomas e cultivos.

ANEXO A - NORMAS DA REVISTA ADVANCES IN WEED SCIENCE

Type of Manuscript: (Research article – maximum of 7,000 words, Review Article – maximum of 9,000 words, Short Communication – maximum 3,000, or Opinion – maximum 2,000 words). Manuscript size includes the whole document, including references.

Running Title: A short title for the running header that does not exceed 40 characters, including the spaces.

Title: The title must reflect the work's content and have no subtitles, abbreviations, formulas, symbols and commercial names. Scientific names should be included in the title only if common-English names of the species are not available. The title must be formatted in upper case, in bold. Avoid description of geographical localization unless it is directly related with the results.

AuthorFirstname M. Lastname[a], AuthorFirstname M.M. Lastname[b] and AuthorFirstname M. Lastname[c,*]

[a] Affiliation 1 (Position, Department, College, University, City, State, Country); Full Author Name ORCID: https://orcid.org/0000-000X-XXX-XXX; e-mail@e-mail.com;

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Highlights

- Describe three major highlights of the manuscript, with a maximum of 110 characters each, including spaces.

- The highlights should be related with the main findings of the study and not about methodology, analysis, or general ideas.

Tips to build effective highlights: The highlights are the opportunity of authors to flag the article distinctiveness and describe the key messages for the readers. Make an exercise considering yourself as the reader and ask if you would pay attention on the paper. Write the highlights after all other parts of the article but revise and rewrite after that. Avoid using details, description of methodology and obvious information. Focus on summarizing the fundamental question, what is the problem and why is important. Avoid describing the results itself but explain where it fits. The key strategy is considering that the highlights must be short and comprehensive. Avoid using vague words like effect, result, influence, cause, association, etc. and prefer direct statements using increase or decrease, for example. Considering the readers have agricultural background and avoid weed science jargons as possible. Although the highlights are short messages, construct it as full grammatical sentences. A standard composition is the first highlight for describing the core problem, after stating the main findings and close with the contribution of the paper. **Please Remove this comment after reading.**

Abstract: Maximum of 250 words, including the following subtopics:

Background: State the importance of the research and present previous findings.

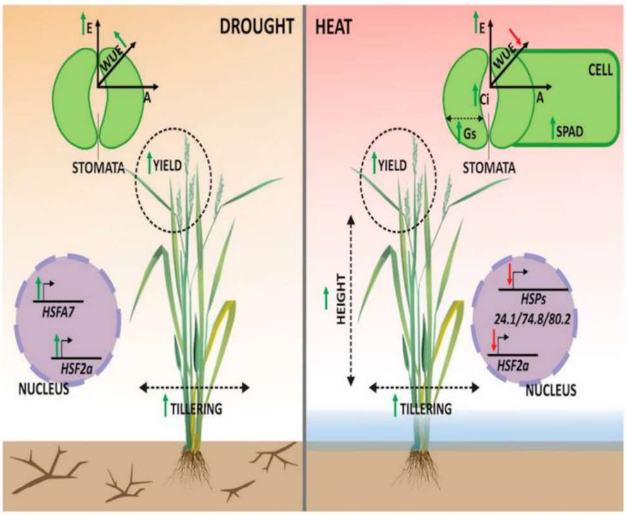
Objective: State the goals of the manuscript.

Methods: Summarize the methodology and treatments, and experimental design. Inform if the experiments were replicated in time/growing season. Avoid unnecessary details.

Results: Explain the main findings that lead to the conclusion.

Conclusions: List the main conclusions of the manuscript.

Keywords: Provide four to eight keywords. Keywords must be distinct from what is in the title and abstract.



Graphical Abstract: A graphical abstract is a visual summary of the main findings of the research. The graphical abstract is used in the Journal webpage and in social media to promote the manuscript. The authors should build the abstract with the main take-home message the authors want the readers to take. The figure should be formatted in JPG, PNG, or TIFF in high resolution figure (at least 600 DPI) and should measure at least 2000 x 1660 pixels (width x height - keep the proportion if using different size). The graphical abstract should be submitted inside the text and as a separate file in the ScholarOne system. The example above was obtained from: https://www.mdpi.com/2077-0472/11/1/9

Tips to build an effective graphical abstract: The main idea is introducing the subject of the article, summarizing the most important finding and connecting the whole subject. The title, authors, highlights and graphical abstract will be used together for communicating the article in social media and in the journal webpage. Considering the graphical abstract as the visual advertisement of the article. The graphical abstract can be constructed as a flow diagram, a conceptual model, a scheme, or composition of figures. Start by planning the main concepts, after making a sketch and finalize by improving the quality and connections of the information. **Do not use direct figures or results of the article.** A composition of result figures can be used as part of the graphical abstract but remember that usually they are difficult to understand after reading the related text and the legend. Therefore, usually a composition of result figures must be edited to improve the understanding as part of the graphical abstract. The illustrations can be originally drawn or composed using tools available on the internet. – **Please remove this comment after reading**.

Conflict of Interest

Please state if the authors have any conflict of interest to declare regarding the research.

1. Introduction

The Introduction should be one to two pages long and contain the background and justification for the study, stating the importance of the scientific problem. The information provided in the Introduction should be enough to establish the research hypothesis.

Authors should prioritize referencing recent works published in scientific journals, but the citation of classical works is acceptable in a reasonable number. Citation of bulletins or technical circulars (“gray literature”) is not acceptable. In the last paragraph of the Introduction, the authors should present the scientific hypothesis and the study’s objective.

The manuscript should be formatted in page size A4 with a left margin of 3 cm and remaining margins of 2.5 cm; font type Arial, size 11; 1.5 line spacing; pages and lines numbered sequentially. Tables and figures should be included in individual pages at the end of the manuscript.

2. Material and Methods

This section should describe the experimental conditions and methods used so that there is sufficient and detailed information for the work to be replicated. Formulas, expressions, or mathematical equations should be placed in their text line, starting at the page’s left margin. Include references for the statistical methods used and report any data transformations. Statistical significance should be indicated as follows: $p<0.01$ or $p>0.05$ (letter “p” in lower case). Genomic information used for primer design or obtained as results of the study must be deposited in a public database and the accession number must be described.

If needed, Material and Methods and Results and Discussion can be divided in subsections:

Note: the experiment should be repeated in time and/or location. Exceptions will be considered for studies that consist of a series de experiments where the core treatments are common.

2.1. Subsection of Material and Methods

2.2.1. Subsubsection of Material and Methods

- Authors can include only figures and tables which are properly cited in the manuscript; Each table and figure should be placed in a separate page at the end of the manuscript;
- Figures and graphics must be cited in the text in numerical order, without abbreviations; if the figure is identified with a lowercase letter (for example, Figure 1a), it should be cited in the text with the same format;
- The table or figure and its respective caption should be self-explanatory, without the need for using the main text for their understanding.
- The titles of tables and figures should be clear and complete and include the species' name (common or scientific) and dependent variables.
- **Units of the variables analyzed must follow the International System of Units** and are positioned at the top of the columns in the tables, outside the table header. In composite units, quantities must be separated by space, and the denominators must be indicated in superscript. Examples: µmol m^{-2} s^{-1}; kg ha^{-1}.
- Values represented in tables and figures are indicated according to the English format, with a period (.) separating decimals and with commas (,) separating groups of thousands (1,000 = one thousand; 1,000,000 = one million; 1,000.45 = one thousand and forty-five hundredths).
- Herbicide rates, when first mentioned in the text, it must be expressed on g ha^{-1} of acid equivalent (ae), or active ingredient (ai). Example: glyphosate was applied at 1440 g ha^{-1} ae and clomazone was applied at 900 g ha^{-1} ai. After that, doses must be described as g ha^{-1} for both herbicide types.
- Tables must be provided with their respective captions with a period (.) at the end of the caption.
- Tables should be formatted as follows:

- Titles must be self-explanatory and contain all the information necessary for understanding the values presented and the statistical analyses used;
- The content must be editable in the **Table** option of Microsoft Word, without lateral borders or separation lines between columns;
- The tables must have only three continuous lines borders (two to mark the table header and one at the end of the table). If necessary, a fourth dashed lines borders can be included to separate the necessary statistical parameters, as shown below:
- Numbers in the tables must be aligned with the decimal separator in the column;

- Graphs, drawings, maps, and photographs used to illustrate the text are considered figures;
- Figures formatting: Figures should be square rather than rectangles. The square format will fit better in a single column in the published paper. We encourage the authors to use colors in the figures. After acceptance, it will be reformatted to the standard colors of the journal (Green/Gray);
- Figures must be included in the text as JPG, PNG, or TIFF in high resolution (at least 300dpi). Figure labels must be typed in Arial font, size 8, regular (not bold). Authors should avoid colors in figures, except for photographs. In the case of composite figures, each section (for example, each graph) should be marked as a separate item ("a, b, c..."), in lowercase letters;
- Scanned figures and tables will not be accepted;

3. Results and Discussion

In the Results and Discussion section, the authors should present the research results and discuss them to evaluate the variables analyzed in light of the study's objectives. The simple comparison of the results with the data presented by other authors does not characterize a discussion. Speculation must be avoided. Data should not be presented redundantly in tables and figures.

Results and Discussion can also be divided in subsections.

3.1. Subsection

3.2.1. Subsubsection

4. Conclusions

This section is mandatory and should focus on the findings of the manuscript, answering the research hypothesis.

Author's contributions

In this section the authors must inform the contribution of each author to the manuscript. Use initials to refer for each author name. The content must state the contribution of each author according to the model:

Conceptualization of the manuscript and development of the methodology: X.X., Y.X., and Z.Z.; data collection and curation: X.X., and Y.X.; data analysis: Z.X., and Y.X.; data interpretation: X.X., Y.X.; funding acquisition and resources: X.X., Y.X., and Z.Z.; project administration: X.X., Y.X., and Z.Z.; supervision: X.X.; writing the original draft of the manuscript: X.X., Y.X., and Z.Z.; writing, review and editing: X.X., Y.X., and Z.Z.;. All authors read and agreed to the published version of the manuscript.

Acknowledgements

Add as necessary. If the material was submitted to specialists that are not authors of the paper, or if materials or samples were borrowed or obtained from different institutions (museums, herbaria, libraries, and other archives), the authors are encouraged to mention them. Authors should avoid personal statements in this section and attain only aspects that directly affected the article's research.

Funding

Authors must disclose all funding sources. The authors are advised to check if there are any funding agencies' requirements and supporting institutions to include their grant/process numbers in this section. The funding includes any monetary assistance to conduct the research, including but not limited: assistantship; fellowship, project funding, article processing charge funding, etc...

If the authors did not receive funding for the research, please add: "This research received no external funding", or

If the authors received funding for the research please add all the funding sources adding: "This research was funded by NAME OF FUNDER, grant number XXX" and "The article processing charge was funded by XXX".

References

References should follow the **Vancouver** (author-date) style, i.e., they should be in lowercase followed by the year of publication. In the case of references with three to six authors, cite the first author in the main text followed by "et al.", and list all authors in the references section, separated by commas. If there are more than six authors, list the first six authors, followed by the expression "et al." In the case of several works by the same author, with the same date, lowercase letters are used in the reference, in alphabetical order, following the date, to differentiate the several publications in the bibliographic list, as follows: (1992a,b). Personal communications and unpublished papers or reports should be cited in footnotes and should not appear in the References. Citation of articles published in proceedings of scientific events will no longer be accepted. Independent on the original language, all citations must be in English, stating the original language at the end (see example).

Only references strictly necessary for understanding the article should be cited, up to a maximum of 30 references (see section 4.1 of this document). The list of references should start on a new page.

We recommend preparing the references with a bibliography software package, such as EndNote, ReferenceManager or Zotero to avoid typing mistakes and duplicated references. Include the digital object identifier (DOI) for all references where available.

References should be formatted following the models below, presented in alphabetical order of authors and, within this, in chronological order of publication; the titles of journals should be abbreviated. Include only works cited in the text, tables, or figures, as follows.

In the text, the format should be done as the examples:

a. Journal articles:

- ARTICLES WITH UP TO SIX AUTHORS: Cite all authors
    - In the text: (Gaines and Sam, 2011)
    - In the references:
    - Author(s). Title. Journal abbreviated name. year;volume(issue):pages. Available from: DOI
    - Gaines TA, Sam M. The quick and the dead: a new model for the essential role of ABA accumulation in synthetic auxin herbicide mode of action. J Exp Bot. 2020;71(12):3383–5. Available from: https://doi.org/10.1093/jxb/eraa178

- Observation: Each article must present the valid DOI

- ARTICLES WITH MORE THAN SIX AUTHORS:
    - In the text: (Viero et al., 2009)
    - In the references:
    - Author(s). Title. Journal abbreviated name. year;volume(issue):pages. Available from: DOI
    - Viero JLC, Schaedler CE, de Azevedo EB, Dos Santos JVA, Scalcon R de M, de David DB, et al. Endozoochorous dispersal of seeds of weedy rice (Oryza sativa L.) and barnyardgrass (Echinochloa crus-galli L.) by cattle. Cienc Rural. 2018;48:e20170650. Available from: https://doi.org/10.1590/0103-8478cr20170650
    - Observation: Each article must present the valid DOI

b. Books:

- Citation of books and book chapters should be avoided. However, when such a citation is unavoidable, it must be made as follows:
- Author(s) of the book. Title. Edition. Place of publication: Publisher; year of publication.
- Senseman S.A. Herbicide handbook. 9th ed. Lawrence: Weed Science Society of America; 2007.

c. Dissertations and Thesis:

- Citation of dissertations and theses should be avoided. Try to cite instead their resulting articles published in full in indexed journals. Cite only very recent dissertations/theses, when articles have not yet been published, as follows:
- Author. Title [Type of document]. Place: Institution where it was presented; year. Available from: link to the webpage
- Ribeiro DN. [Characterization of the glyphosate resistance in Lolium multiflorum (Lam.)] [thesis]. Piracicaba: Escola Superior de Agricultura “Luiz Armando de Queiroz”; 2008. Portuguese. Available from: http://bdtd.ibict.br/vufind/Record/USP_057b21cae41e9974c17901e2b25b94fa

d. Citing publications original in other languages

When citing publications original in other languages the authors should cite the title in English between square brackets and the language at the end of the citation. Examples:

- Avila LA, Marchezan M, François T, Cezimbra DM, Souto KM, Refatti JP. [Injury caused by the formulated mixture of the herbicide imazethapyr and imazapic in ryegrass as affected by soil moisture]. Planta-daninha. 2010;28:1041–6. Portuguese. Available from: http://doi.org/10.1590/S0100-83582010000500012

Comments: Tables and figures should be included in individual pages at the end of the manuscript. In addition, each table and figure need to be uploaded in the system in separate files; the figures must be sent in the original editable file (the original format the authors used to create the figures – Sigma Plot, Excel, R, etc…).

Table 1. Tables should be placed in the main text near to the first time they are cited. Titles must be self-explanatory and contain all the information necessary for understanding the values presented and the statistical analyses used.

Title 1	**Title 2**	**Title 3**
entry 1	data[1]	data
entry 2	data	data
entry 3	data	data

[1] Tables may have a footer.

Tables should be formatted as follows:

- Titles must be self-explanatory and contain all the information necessary for understanding the values presented and the statistical analyses used;
- The content must be editable in the **Table** option of Microsoft Word, without lateral borders or separation lines between columns;
- The tables must have only three continuous lines borders (two to mark the table header and one at the end of the table). If necessary, a fourth dashed lines borders can be included to separate the necessary statistical parameters, as shown below:
- Numbers in the tables must be aligned with the decimal separator in the column;

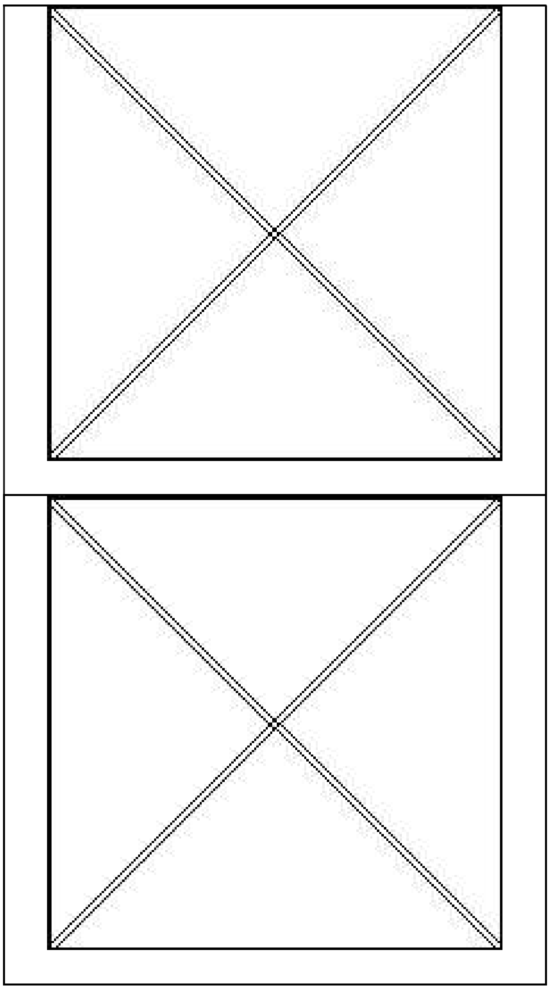


Figure 1. This is a figure. Figure can be divided in panels as in this example: (**a**) Description of what is contained in the first panel; (**b**) Description of what is contained in the second panel. Figures title must be self-explanatory and contain all the information necessary for understanding the values presented and the statistical analyses used.

Figures formatting: Figures should be square rather than rectangles. The square format will fit better in a single column in the published paper. We encourage the authors to use colors in the figures. After acceptance, it will be reformatted to the standard colors of the journal (Green/Gray);

Figures must be included in the text as JPG, PNG, or TIFF in high resolution (at least 300dpi). Figure labels must be typed in Arial font, size 8, regular (not bold). Authors should avoid colors in figures, except for photographs. In the case of composite figures, each section (for example, each graph) should be marked as a separate item (“a, b, c…”), in lowercase letters;

Scanned figures and tables will not be accepted;

ANEXO B - NORMAS DA REVISTA BRASILEIRA DE ENGENHARIA AGRÍCOLA E AMBIENTAL

INSTRUCTIONS TO AUTHORS

The norms of the Brazilian Journal of Agricultural and Environmental Engineering (Agriambi), presented herein, are subject to modifications over time; thus, we suggest the authors to consult them at the moment of the submission of their manuscripts. The manuscripts must not have been sent to any other journal and will be selected for evaluation by the reviewers only if totally within the norms of this Journal.

Authors must have their manuscripts reviewed by a specialist for orthography and grammar correction of English before submitting or returning them to the Journal, at any step of the process. Manuscripts with orthography problems will be negatively affected in the evaluation and may be rejected for this reason. Articles that directly or indirectly address studies involving humans and animals, in their entirety or part of them, including the management of information or materials in all areas of knowledge, must inform in the Material and Methods item that the study was approved by the committee of ethics involving human beings and/or ethics committee in the use of animals, with the name of the Committee, Institution and Process number. Manuscripts addressing research with experiment will only be accepted for publication if at least one of the following criteria is met: a) experiment with minimum of 20 plots; b) experimental design with number of residual degrees of freedom equal to or higher than 10; and c) treatments must have at least three replicates. Scientific manuscripts that describe research results obtained more than eight years ago will not be accepted for publication. Authors must inform, in the items Abstract, Resumo and Material and Methods, the period and place (including geographical coordinates and altitude only in the Material and Methods item) of the research and, in the case of research with experiment, the experimental design, treatments and the number of replicates. Manuscripts subdivided into parts I and II must be submitted together, since they will be sent to the same reviewers.

Language and study areas

The scientific articles submitted to Agriambi Journal must be original and unpublished, and written in English. For articles accepted for publication, authors will be asked to provide English proofreading through one of the companies accredited by the Journal, according to the list available at www.agriambi.com.br. Even though the article submission is only in English, the manuscript must also have Title, Abstract and Key words in Portuguese, which should come after the Title, Abstract and Key words in English. All words in figures should be translated into English, and numeric values in tables, figures and in the text should have a dot instead of a comma separating the integer from the decimal. The name of Brazilian institutions, such as departments, universities and institutes must remain in original language. The manuscripts must result from researches in one of the following areas: Soil, Water and Plant Management, Irrigation and Drainage Engineering, Agricultural Meteorology and Climatology, Storage and Processing of Agricultural Products, Environmental Control and Management (this area includes only manuscripts describing researches on environmental control and management in the agricultural context), Rural Construction and Ambience, Automation and Instrumentation, Agricultural Machines and Energy in Agriculture. The Journal accepts contributions only in the modalities of Scientific Paper and Literature Review, that is, contributions must describe the results of scientific research carried out. Contributions in the modalities of Preliminary Note and Technical Note are not accepted by the Journal. In addition, it should be pointed out that the Journal does not publish manuscripts of extension and/or purely technical nature; manuscripts simply describing the development of software, spreadsheets and mobile applications will not be accepted for publication.

Sequence of items in the manuscript

a) Title in English: it encompasses the content and the objective of the study, with maximum of 15 words, including articles, prepositions and conjunctions. Only the first letter of the first word must be capitalized. However, when the title has a subtitle, i.e., followed by colon (:), the first letter of the first word of the subtitle (to the right of the colon) must be capitalized. The title must not include the words effect, evaluation, influence or study.

b) Name(s) of the author(s):

- The manuscript file sent in the submission must not contain the name(s) of the author(s) or the identification of the institution(s), because this file will be made available to the reviewers in the system, ensuring blind peer evaluation. However, the name(s) of the author(s) will be informed to the system by the corresponding author during the submission. The corresponding author must already be registered as author in the SciELO Publication system before beginning the submission process. It is necessary that the corresponding author defined his position in the authorship of the article in relation to the other authors.

- There is no limitation on the number of authors in the article.

- After submission of the article through the SciELO System, subsequent changes to the authors' names are not allowed, whether in sequence, substitution or addition.

c) Institution and place where the research was developed.

d) Highlights.

Insert three highlights describing the main findings or results of the research, however, the words used in this description should not be the same as the conclusions. Each highlight must have a maximum of 125 characters with spaces. See examples of highlights in articles recently published in Agriambi Journal.

e) Abstract: maximum of 250 words with no abbreviations.

f) Key words: minimum of three and maximum of five, not included in the Title, separated by commas and with only lowercase letters.

g) Title in Portuguese: the same standardization of the title in English.

h) Resumo: maximum of 250 words, an exact translation of the Abstract.

i) Palavras-chave: the same standardization of the Key words, and an exact translation of this item.

j) Introduction: the relevance of the study must be highlighted, including through literature review, in a maximum of one page. The Introduction must not have equations, tables, figures or basic theoretical text on a specific subject; instead, there should be a text referring to research results. The last paragraph must present the objective of the study.

k) Material and Methods: it must provide indispensable information that allows the replication of the research by other researchers.

l) Results and Discussion: the obtained results must be discussed and interpreted based on the literature. Tables and figures must not present the same results.

m) Conclusions: must be numbered and written succinctly, i.e., with no comments or additional explanations, based only on the presented results and with no abbreviations.

n) Acknowledgments (optional)

o) Literature Cited:

- The submitted manuscript must have at least 80% of journal citations, with a minimum of 40% from the last five years.
- Bibliographic citations such as "apud" or "cited by" are not be accepted, i.e., citations must be only of the original references.
- Citations of in-press articles, personal communications, folders, handouts, monographs, final course assignments, technical reports and works published in congresses, dissertations and thesis are not accepted in the elaboration of the manuscripts.
- In certain contextualization, the citation of more than one bibliographic reference should first follow the chronological order and, then, the alphabetical order of the authors; in the citation of more than one bibliographic reference of the same authors, his/her name must not be repeated; however, the publication years must be separated by a comma.
- The manuscript must have a maximum of 30 bibliographic references. For the contribution in the modality of Literature Review, there is no maximum limit for the number of bibliographic references.

The contribution in the form of a Literature Review must have the following sequence: Title, Abstract and Key words in English and then Title, Abstract and Key words in Portuguese, Introduction, Items on the topics of the review, Conclusions, Acknowledgments (Optional), Literature Cited.

Text editing

a) Word of Microsoft Office 2016: The manuscript must be edited only in this version of Microsoft Word.

b) Text: font Times New Roman, size 12. The text must not contain bold or italic words, except for the title, items and sub-items, which must be in boldface, and the scientific names of plant and animal species, which must be in italic. Equations, tables and figures must not contain italic or bold words. The equations should be written using the software MS Equation.

c) Spacing: the text must be double-spaced in the entire manuscript.

d) Paragraph: 0.5 cm.

e) Page: size A4, portrait orientation, top and bottom margins of 2.54 cm and left and right of 3.00 cm, with a maximum of 20 pages, including tables, figures and the cited literature. Pages and lines must be numbered; line numbering must be continuous, i.e., continuing from the previous to the next page.

f) All the items must be capitalized, in boldface and centered, except Abstract and Resumo, which must be aligned to the left, and Key words and Palavras-chave left-aligned with only the first letter capitalized. The sub-items must be aligned to the left, in boldface, with only the first letter capitalized.

g) Units must be expressed in the ISU (International System of Units) and the scientific terminology must follow the international conventions of each area.

h) Tables and Figures (graphs, maps, images, photographs, drawings):

- Tables and figures must be self-explanatory and have width of 8.75 or 18 cm, with font Times New Roman, size 9, and inserted right below the paragraph in which they are cited for the first time. Examples of citations in the text: Figure 1; Table 1. Figures with virtually the same title must be grouped in one single figure, creating, however, an indication of differentiation. The indicating letter of each sub-figure in a grouped figure must be capitalized and followed by a period (Example: A.), placed in the upper left corner of the figure. Grouped figures must be cited in the text as follows: Figure 1A; Figure 1B; Figures 1A and B. Tables and figures with width of 18 cm will exceed left and right margins of 3.0 cm, which is not a problem.

- Tables must not contain vertical dashed lines and should have the minimum possible of horizontal dashed lines. Numbers in the columns must be aligned by the last digit. Example of the title, which must be above the table: Table 1. Selected INMET stations (without a fullstop at the end). In tables with comparison of means, according to statistical analysis, there must be a space between the number (mean) and the letter.

- Figures must not contain borders, and the curves (in case of graphs) can be in color, but always using different data markers, because labels based only on colors will disappear when photocopied. Example of the title, which must be below the figure: Figure 1. Accumulated soil loss as a function of the application time of simulated rain (without a fullstop at the end). In order to avoid redundancy, figures must not contain the data presented in tables. Graphs, diagrams (curves in general) must come as a vector image. Bitmap figures must have a minimum resolution of 300 bpi. The authors should ensure the quality of resolution, aiming at a good comprehension of the figures.

- Legends, axis and axis titles of the figures must contain Times New Roman font and should not be italicized or bold. In case of equal axis titles for Figures 1A, B, C ... center the axis title for all figures. Figures with subtitles should have different markers for each curve, because figures with color-only subtitles, when printed in black and white the subtitles disappear, making it impossible to identify each curve.

- In case of research with treatments, inform in table or in figure, the value of the coefficient of variation (CV) for each variable evaluated. When there is regression analysis, provide, in table or figure, for each equation the value of the coefficient of determination (R^2) followed by the value of the CV; there should be no figures having curves with R^2 lower than 0.60; in these cases, include the equation and the respective value of R^2 in the discussion of the results. Place in each regression equation presented in table or figure, the symbology of the significance of the coefficients (* or ** or ns), placing it in superscript between the values of the coefficients and the variable. Place a footnote in Times New Roman 9 font in the figure or table informing the probability of significance of the coefficients of the equation and the statistical test adopted; example: ** - Significant at $p \leq 0.01$ by the F test. Each experimental point plotted in the figure must have, through a vertical bar, the representation of the standard error or standard deviation, and a footnote in Times New Roman 9 font, must inform if it is the standard error or standard deviation.

Examples of citations in the text

a) When the citation has only one author: Oliveira (2020) or (Oliveira, 2020).

b) When the citation has two authors: Thomaz & Fidalski (2020) or (Thomaz & Fidalski, 2020).

c) When the citation has more than two authors: Anjos et al. (2022) or (Anjos et al., 2022).

d) When the work is authored by an institution/company, the citation must be its acronym, in capital letters: EMBRAPA (2020) or (EMBRAPA, 2020).

e) When there are citations with one or two authors, having the same authors and being from the same year: Oliveira (2020a); Oliveira (2020b); Thomaz & Fidalski (2020a); Thomaz & Fidalski (2020b).

f) When there are citations with more than two authors, having the same name as the first author and being from the same year: Liu et al. (2020a); Liu et al., 2020b); (Liu et al. (2020a,b).

List of Literature Cited

The references cited in the text should be arranged in the Literature cited at the end in alphabetical order starting with the last name of the first author and, in ascending chronological order, and contain the names of all authors. Put at the end of each reference listed the link to its doi for access.

The following are examples of formatting:

a) Books

Rostagno, H. S.; Albino L. F. T.; Hannas, M. I.; Donzele, J. L.; Sakomura, N. K.; Perazzo, F. G.; Saraiva, A.; Teixeira, M. L.; Rodrigues, P. B.; Oliveira, R. F.; Barreto, S. L. T.; Brito, C. O. Tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais. 4.ed. Viçosa: UFV, 2017. 488p

MAPA - Ministério da Agricultura, Pecuária e Abastecimento - Manual de métodos analíticos oficiais para fertilizantes e corretivos. 1.ed. Brasília, 2017. 240p.

Taiz, L.; Zeiger, E.; Moller, I. M.; Murphy, A. Fisiologia e desenvolvimento vegetal. 6.ed. Porto Alegre: ArtMed, 2017. 888p

b) Book chapter

Motta, A. C. V.; Melo, V. F. Química dos solos ácidos. In: Melo, V. F; Alleoni, L. R. F. Química e mineralogia do solo: Conceitos básicos e aplicações. Viçosa: Sociedade Brasileira de Ciência do Solo. 2019. Cap.1, p.1009-1076.

Da Matta, F. M.; Ronchi, C. P.; Eduardo Ferreira Sales, E. F.; Araújo, J. B. S. O café conilon em sistemas agroflorestais. In: Ferrão, R. G.; Fonseca, A. F. A. da; Ferrão, M. A. G.; De Muner, L. H. Café conilon, Vitória: Incaper, 2017. Cap.19, p.481-494.

c) Journals

Anjos, F. A. dos; Ferraz, R. L. de S.; Azevedo, C. A. V. de; Costa, P. da S.; Melo, A. S. de; Ramalho, V. R. R. de A. R. Relationship between physiology and production of maize under different water replacements in the Brazilian semi-arid. Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.21-27, 2022. https://doi.org/10.1590/1807-1929/agriambi.v26n1p21-27

Moura, M. de P.; Ribeiro Neto, A.; Costa, F. A. da. Application of satellite imagery to update deptharea-volume relationships in reservoirs in the semiarid region of Northeast Brazil. Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.44-50, 2022. https://doi.org/10.1590/18071929/agriambi.v26n1p44-50

d) Software references

SAS - Stastistical Analysis System. User's guide statistics. 9.ed. Cary: SAS Institute, 2002. 943p.

R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2017. Available on: <https://www.r-project.org/>. Accessed on: Feb. 2020.

e) Other reference formats

INMET- Instituto Nacional de Meteorologia. Informações sobre as condições climáticas em UberabaMG. 2019. Available on: <http://www.inmet.gov.br/>. Accessed on: Jun 2021.

CONAB - Companhia Nacional de Abastecimento. Acompanhamento da safra brasileira de grãos: safra 2019/2020. Available on: <http://www.conab.gov.br/Conabweb/download/pdf>. Accessed on: Jun 2021

FAO - Food and Agriculture Organization - FAOSTAT (2017) Crops. Cowpeas, dry. Available on: <https://faostat3.fao.org/home/index.html#DOWNLOAD>. Accessed on: Nov. 2018.

MAPA. Ministério da Agricultura, Pecuária e Abastecimento. Brasília: MAPA, 2020. Available on: < https://agrofit.agricultura.gov.br/ >. Accessed on: Mar. 2021.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. Uso de informações ambientais na modelagem e interpretação da interação genótipo x ambiente. 1.ed. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2020. 46p.

Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M. Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: Food and Agriculture Organization, 1998. 300p. Drainage and Irrigation Paper, 56

IPEA - Instituto de Pesquisa Econômica Aplicada. Sobre a agricultura irrigada no semiárido: uma análise histórica e atual de diferentes opções de política. Texto para Discussão, 2018. 56p. https://www.ipea.gov.br/portal/

References that have one or two authors, having the same authors and being from the same year, and references that have more than two authors, having the same name as the first author and being from the same year, must be identified in the list of literature cited. after the year, by the letters a, b, etc.

Further information on standardization of manuscripts

a) Do not use a fullstop after Palavras-chave, Keywords and titles of tables and figures.

b) In the description of the parameters and variables of an equation, a hyphen (-) must separate the symbol from the description, and a semicolon (;) must be used at the end of each description, with a fullstop (.) after the last one. The number of an equation must be in parentheses and aligned to the right: example: (1). The equations must be cited in the text, according to the following examples: Eq. 1; Eqs. 3 and 4.

c) All the letters in an abbreviation must be capitalized; however, in the full name of an institution, only the first letter of each word must be capitalized.

d) Examples of the format of units

25% (The % is the only unit that must be next to the number); 45 mL; 5 L; 27 °C; 70 kg ha^{-1}; 6.1 kJ mol^{-1}; 11.46 t ha^{-1}; 45 tons; 10 million hectares; 15:00 h; 30 s; 45 min; 10 hours; two hours (0 to 9 – spelled out, except number with unit or if it is accompanied by a number greater than 9); 2, 3 and 14 hours; 2 mm per day; 0.0015 g g^{-1} per day; 2 x 3 (must be separated); 45.2-61.5 (must be together); 6.0 and 13.0 Mg ha^{-1} (numerical values in a row that have the same unit, put the unit only in the last value); 0.14 m^3 min^{-1} m^{-1}.

e) When pertinent, numerical values in the text, tables and figures should have a maximum of two decimal places.

f) The titles of the listed bibliographies must have only the first letter of the first word capitalized, except for proper names. The title of events must have only the first letter of each word capitalized.