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ECONOMIC WEED THRESHOLD OF *Maranta sobolifera* PLANTS IN OFF-SEASON CORN

Abstract – *Maranta sobolifera* (Caeté) has tolerance to chemical management and has spread consistently on the agricultural areas of the western region of Paraná over the years. However, there is little information about its potential to interfere with the main agricultural crops. This study aimed to estimate the economic weed threshold (EWT) of *M. sobolifera* plants in commercial areas of production of off-season corn. There were losses in grain yield of up to 303.7 kg plant^{-1} of *M. sobolifera*. Considering an acceptable loss in grain yield of 614.05 kg ha^{-1}, EWT estimates varied from 2.0 to 41.2 plants m^{-2} of *M. sobolifera*. In practice, these data can be used in no-till areas, where complementary control is necessary at the crop post-emergence (V4-V6), after desiccation of the area, to maintain weed density at tolerable levels until the end of the cycle. In addition, factors such as the use of less competitive hybrids, obtaining the maximum productive potential of the crop, increasing the value of the harvested product and the efficiency of chemical management (desiccation) and a reduction in the cost of control contribute to the reduction of the EWT and make the adoption of management practices of *M. sobolifera* more profitable in off-season corn.

Keyword: Weed interference, decision making, integrated management, *Zea mays*

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NÍVEL DE DANO ECONÔMICO DE *Maranta sobolifera* NA CULTURA DO MILHO SAFRINHA

Resumo – A *Maranta sobolifera* (Caeté) apresenta tolerância ao manejo químico e sua disseminação nas áreas agrícolas da região oeste paranaense vem aumentado a cada ano. Porém, existem poucas informações sobre seu potencial de interferência nas principais culturas agrícolas. Objetivou-se estimar o Nível de Dano Econômico (NDE) de plantas de *M. sobolifera* em áreas comerciais de cultivo de milho safrinha. Houve perdas na produtividade de grãos de até 303,7 kg planta^{-1} de *M. sobolifera*. Considerando a perda aceitável na produtividade de grãos de 614,05 kg ha^{-1} as estimativas do NDE variaram entre 2,0 a 41,2 plantas m^{-2} de *M. sobolifera*. Na prática, estes dados podem ser utilizados em áreas de plantio direto que necessitam de complementação de controle na pós-emergência do milho (V4-V6), após a dessecação da área, visando manter a densidade da planta daninha em níveis toleráveis até o final do ciclo da cultura. Além de que, fatores como o uso de híbridos menos competitivos, obtenção do potencial máximo produtivo da cultura, aumento no valor do produto colhido e da eficiência do manejo químico (dessecação) e a diminuição do custo de controle contribuem para a redução do NDE, e tornam mais rentável a adoção de práticas de manejo de *M. sobolifera* no milho safrinha.

Palavras-chave: Mato interferência, tomada de decisão, manejo integrado, *Zea mays* L.

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In Paraná, especially in the state's western region, off-season corn, or second-crop corn, has been cultivated in the summer-autumn period (January to June) in succession to soybean primary crop season (Gonçalves et al., 2008). Despite the weather instability that is common at this time of the year, with the occurrence of long periods of drought at the early stage of development of the plants and frosts at the end of the cycle, the use of adapted hybrid species has provided satisfactory yield levels, with an average of 5.5 t ha^{-1} (Shiroga & Gerage 2010; IBGE, 2021). However, weed interference during the development of corn plants represents a major limiting factor in achieving high yield levels and ensuring farm profitability.

Corn losses can be as high as 65% due to competition with weed plants (Gantoli et al., 2013). Nevertheless, the degree of interference varies according to the floristic composition and density of species in the weed community and the tolerance of the cultivar/hybrid plant to weed competition. For example, a weed community comprised of *Ipomoea grandifolia* (2 plants m^{-2}), *Commelina benghalensis* (4.2 plants m^{-2}), and *Cenchrus echinatus* (92 plants m^{-2}) reduced corn grain yields by 23% (Dan et al., 2010), while a monospecific infestation of *Digitaria insularis* (5.2 plants m^{-2}) reduced grain yields by 36% (Gemelli et al., 2013).

In South Brazil, a species commonly known by farmers as 'Caeté' (*Maranta sobolifera* L. Andersson) is a weed plant known to be of difficult control (Brighenti et al., 2006), and in the croplands in western Paraná, the occurrence of this species have increased considerably (Salvalaggio et al., 2017). There have also been reports of *M. sobolifera* in Paraguay, a species expanding over agricultural areas (Arrúa et al., 2009). *M. sobolifera* of the family Marantaceae, found initially in shady areas of forest edges, is an herbaceous perennial plant and reproduces preferably via rhizomes (Forzza, 2007). It has been claimed that the conventional tillage system adopted by some farmers to break up compact soil or the exchange of agricultural implements by several producers may favor the dissemination of rhizomes of this species to diverse areas.

The potential of interference of *M. sobolifera* in annual crops has not been addressed in the literature, mainly focusing on the impact of the Economic Weed Threshold (EWT) of this weed species on off-season corn. Thus, the hypothesis of this work is based on the fact that *M. sobolifera* plants can cause significant losses in off-season corn grain yields and that determining EWT can help farmers decide on the most profitable management strategies (Vidal et al. 2010; Kalsing & Vidal, 2010).

This study aimed to assess the interference caused by different densities of *M. sobolifera* in off-season corn grown in commercial areas in four municipalities in western Paraná.

Material and Methods

The study was carried out during the off-season corn crop in 2018 in six commercial crop areas located in the municipalities of Marechal Cândido Rondon, Missal, São Miguel do Iguaçu, and Serranópolis do Iguaçu in the western region of the state of Paraná (Figure 1).

Location and description of the experimental sites

AREA 01 - Marechal Cândido Rondon-PR: (Date of assessment: July 16, 2018). The site is located at coordinates 24° 35.879' S and 054° 04.861' W and altitude of 293 m. The cultivar used was AS 1777 PRO 2, a very early maturing hybrid species

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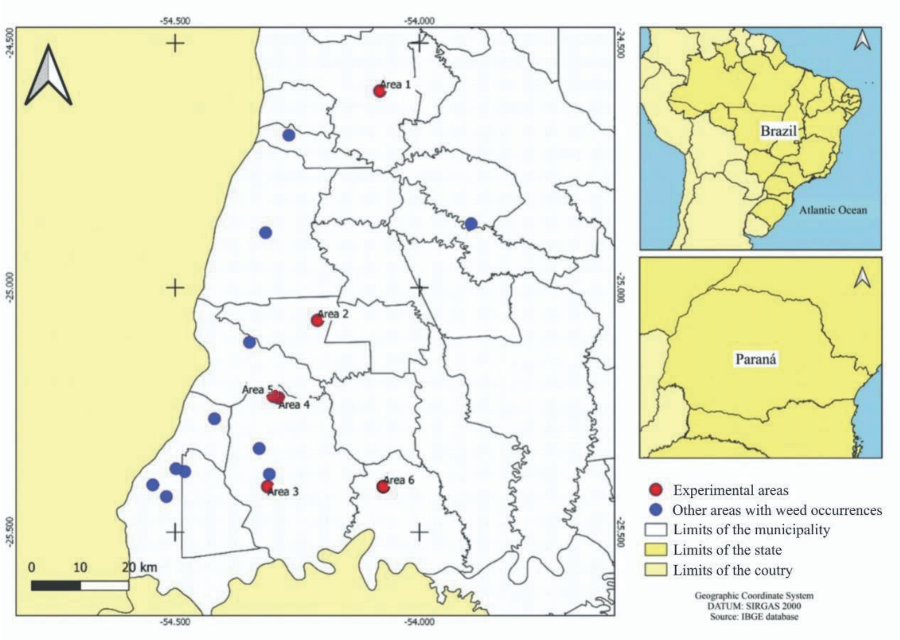

Figure 1. Location of the experimental areas (red spots) and where *M. sobolifera* plants were found in off-season crop corn cultivations (blue spots) in western Paraná. Brazil, 2018.

(130 – 140 days).

The hybrid corn cultivar was sown on Feb 20, 2018, with a population of 60 thousand plants per hectare, base fertilization with 290 kg ha^{-1} of 14 – 18 – 18 NPK fertilizer, spacing of 0.50 m between lines. The land was not tilled in the last two years before this study and cultivated with successions of soybean/ corn crops.

The chemical analysis indicated the following characteristics: pH ($CaCl_2$) = 5.17; O.M. (g dm^{-3}) = 27.22; P (mg dm^{-3}) = 6.10; H+AL, K, Ca, Mg, BS and CEC ($cmol_c$ dm^{-3}) = 5.35; 0.25; 5.43; 2.37; 8.05; 13.40 respectively; V% = 60.07; the soil textural composition is 39.80% clay, 48.76% silt and 11.43% sand.

AREA 02 - Missal-PR: (Date of assessment: July 20, 2019). The land is located at coordinates 25° 04.027' S and 054° 12.528' W and altitude of 314 m. The cultivar used was SWS 9110 VT PRO 3, a very early maturing hybrid corn (130 – 140 days).

The corn cultivar was sown on Feb 15, 2018, at a density of 60 thousand plants/ hectare. Base fertilization consisted of 250 kg ha^{-1} of 11 – 16 – 11 NPK fertilizer; spacing of 0.50 m between lines. The area has been cultivated in soybean/corn successions for more than 12 years.

The chemical analysis indicated the following characteristics: pH ($CaCl_2$) = 5.30; O.M. (g dm^{-3}) = 27.34; P (mg dm^{-3}) = 33.54; H+AL, K, Ca, Mg, BS and CEC ($cmol_c$ dm^{-3}) = 3.73; 0.88; 6.41; 2.67; 9.96; 13.69 respectively; V% = 72.76; the soil is composed of 39.80% clay, 48.76% silt and 11.43% sand.

AREA 03 - São Miguel do Iguaçu-PR (1): (Date of assessment: July 22, /2019). The experimental area is located at coordinates 25° 24.420' S and 054° 18.657' W and altitude of 248 m. The cultivar used

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in the area was AS 1633 PRO 2, an early maturing hybrid species (140 - 150 days).

The cultivar was sown on Feb 23, 2018, at a density of 55 thousand plants/hectare, base fertilization with 310 kg ha^{-1} of 10 – 15 – 15 NPK fertilizer, spacing of 0.50 m between lines. The area has not been tilled for more than 10 years but cultivated with soybean/corn crops successions.

The chemical analysis indicated the following characteristics: pH ($CaCl_2$) = 4.86; O.M. (g dm^{-3}) = 19.50; P (mg dm^{-3}) = 24.90; H+AL, K, Ca, Mg, BS and CEC ($cmol_c$ dm^{-3}) = 5.76; 0.46; 4.80; 1.48; 6.74; 12.50 respectively; V% = 53.92. The soil is composed 39.80% clay, 48.76% silt and 11.43% sand.

AREA 04 - São Miguel do Iguaçu-PR (2): (Date of assessment: July 23, 2019. The farm is located at coordinates 25° 13.549' S and W054° 17.302' W, and an altitude of 231 m. The cultivar used was Syngenta Status Viptera 3, an early maturing hybrid variety (140 - 150 days).

The cultivar species were sown on Feb 25, 2018, at a density of 55 thousand seeds/hectare; fertilization consisted of 300 kg ha^{-1} of 10-15-15 NPK fertilizer; spacing was 0.50m between lines. The area has been cultivated in soybean/corn succession for about 20 years.

The chemical analysis indicated the following characteristics: pH ($CaCl_2$) = 5.00; O.M. (g dm^{-3}) = 23.88; P (mg dm^{-3}) = 14.22; H+AL, K, Ca, Mg, BS and CEC ($cmol_c$ dm^{-3}) = 4.61; 0.53; 5.93; 2.06; 8.52; 13.13 respectively; V% = 64.89; the soil is composed of 36.40% clay, 50.30% silt and 13.30% sand.

AREA 05 - São Miguel do Iguaçu-PR (3): (Date of assessment: July 26, 2019). This site is located at coordinates 25° 13.333' S and 054° 17.950' W, at 229 m of altitude. The experimental area was cultivated with hybrid KWS 9006 VT PRO 3, an early maturing corn cultivar (140 - 150 days).

Sowing was carried out on Feb 26, 2018, with a population of 58 thousand plants/hectare; base fertilization consisted of 320 kg ha^{-1} of 10-15-15 NPK fertilizer; spacing was 0.50 m between lines. The land has been cultivated in soybean-corn succession.

The chemical analysis indicated the following characteristics: pH ($CaCl_2$) = 4.85; O.M. (g dm^{-3}) = 23.31; P (mg dm^{-3}) = 21.75; H+AL, K, Ca, Mg, BS and CEC ($cmol_c$ dm^{-3}) = 5.35; 0.55; 4.72; 1.95; 7.22; 12.57 respectively; V%=57.44; the soil was composed of 66.45% clay, 1535% silt and 18.20% sand

AREA 06 - Serranópolis do Iguaçu-PR: (Date of assessment: Aug 1st, 2019). The area is located at coordinates 25° 24.420' S and 054° 04.441'W, and an altitude of 277 m. The cultivar hybrid used in this area was MG 580 PW, a very early maturing species (130 – 140 days).

Sowing was carried out on Feb 23, 2018, with a population of 54 thousand plants/hectare; spacing was 0.50 m between lines. The area has been cultivated in soybean-corn succession for about 10 years. Base fertilization consisted of 290 kg ha^{-1} of 10 – 15 – 15 NPK fertilizer, and when the corn plants were at the V6 growth stage, cover fertilization with 105 kg ha^{-1} urea was applied.

The chemical analysis indicated the following characteristics: pH ($CaCl_2$) = 5.43; O.M. (g dm^{-3}) = 26.66; P (mg dm^{-3}) = 43.05; H+AL, K, Ca, Mg, BS and CEC ($cmol_c$ dm^{-3}) = 3.36; 0.52; 6.01; 2.51; 9.04; 12.40 respectively; V% =72.91. The soil is composed of 36.40% clay, 50.30% silt and 13.30% sand.

The studied species, Caetê, identified as *Maranta sobolifera* L. Andersson, was deposited in the Herbarium of the Universidade Estadual do Oeste

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do Paraná- UNOP, registered with number UNOP 8719. In each experimental area, at least ten sampling sites ($2m^2$) were examined, having different densities of *M. sobolifera* plants, which were determined at random and without replication, according to the methodology proposed by Sartorato et al. (1996).

The sampling sites with densities varying from 0 to 70 plants m^{-2} of *M. sobolifera* were assigned randomly in the field, according to the population levels found naturally in the areas. In all areas, *M. sobolifera* plants were predominantly regrown after the chemical management at the initial stage of the second-crop corn cycle (V4-V6). After this period, *M. sobolifera* plants coexisted with the off-season corn crop until harvest.

At the harvest of each sampling site, plant densities (plants m^{-2}) and dry matter of *M. sobolifera* plants (g m^{-2}) were determined, corn grain yields (kg ha^{-1}) were estimated, and humidity was corrected to 13%.

The Economic Weed Threshold (EWT) was determined based on grain yields as a function of the *M. sobolifera* plants density by adopting economic factors to establish the criterion of acceptable loss, which was calculated according to formula 1, as follows:

$$\text{Acceptable loss (kg ha}^{-1}) = \frac{\text{CC (R\$ ha}^{-1})}{\text{SPC (R\$ kg}^{-1})} \quad (1)$$

To calculate the EWT, we considered a control cost (CC) of R$ 257.90 ha^{-1} (desiccation management): glyphosate+carfentrazone (1440+30 g ha^{-1}) + R$ 30.00 ha^{-1} as application cost (R$ 115.57 ha^{-1}), and post-emergence management (V4-V6 growth stage): glyphosate+atrazine (1080+2000 g ha^{-1}) + R$ 30.00 ha^{-1} as application cost (R$ 142.33 ha^{-1}). The selling price of the crop (SPC) was R$ 0.42 kg^{-1}, which represented an acceptable loss in grain yield of 614.05 kg ha^{-1}. For future comparisons, the price of the dollar used in this study was R$ 5.60 = US$ 1.00.

The control cost was determined based on the strategy of weed management in corn crops per hectare adopted in western Paraná in the 2018/19 season, and the reference values were obtained from technical support companies and resellers of registered corn products (Agrícola Horizonte Ltda and COAMO Agroindustrial Cooperative), through personal communication.

Each area was analyzed individually, and considering that all areas assessed are located in the same region under similar edaphoclimatic and management conditions, the data obtained were previously subjected to a combined analysis, according to the factors and variables studied, in order to obtain the most significant number of information points (Gazziero et al., 2019).

Data were subjected to regression analysis, choosing the models with a high coefficient of determination (R^2), 95% confidence interval, biological logic, and approval in the normality test. Analysis of variance (ANOVA) for regression preceded each analysis to check for significance in the dataset ($p \leq 0.05$).

Results and Discussion

The increased density of *M. sobolifera* plants increased the dry matter per square meter linearly (Figure 2), except in the data shown for Marechal Cândido Rondon (Figure 2A), which exhibited a sigmoidal behavior. In this area, the maximum accumulated dry matter was 65.8 g m^{-2}, of which 50% was obtained at a density of 15.7 plants m^{-2}.

Dry matter accumulation rates corresponded to 1.1; 0.9; 5.3; 1.0 and 2.1 g $plant^{-1}$ m^{-2} for the areas located in Missal, São Miguel do Iguaçu (1), São Miguel do Iguaçu

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(2), São Miguel do Iguaçu (3) and Serranópolis do Iguaçu, respectively.

The highest dry matter accumulation of *M. sobolifera* plants was found in São Miguel do Iguaçu (2), with 263.9 g m^{-2} for a maximum density of 50 plants m^{-2} (Figure 2D). In the other areas studied, the maximum dry matter accumulation ranged from 65.0 to 88.6 g m^{-2}, for maximum densities of 29 and 71 plants m^{-2}, respectively. Variations in the maximum accumulation of dry matter of *M. sobolifera* plants found at different densities can be explained by the inherent genetic diversity in weed populations and different plant ages at the time of harvest, in addition to soil fertility and climate (rainfall rate) in each area and the tillage system used by farmers.

In general, the accumulated rate of dry matter of *M. sobolifera* plants found in the six areas assessed was 1.7 g $plant^{-1}$ (Figure 3). There was statistical significance in the assessed data (p>0.01), despite the low coefficient of determination of the adjusted linear model. However, there was an increase in the accumulated dry matter as the plant densities increased, and these results may correlate with the proportional yield loss of corn hybrids (Figure 4). Similar results were also found by Gazziero et al. (2019), determining soybean yield losses caused by competition with *Digitaria insularis*.

In addition to the data relating to weed density (plant m^{-2}), the parameters relating to dry matter (g m^{-2}), leaf area (cm^2 m^{-2}), and soil cover (%) show a high correlation with potential production losses of food crops and can be used for determination of EWTs (Galon et al., 2019; Frandoloso et al., 2020). However, it is believed that the use of EWT based on weed plant densities has higher practical applicability in the field for being easy to be determined by monitoring and does not depend on the availability of complex, costly equipment.

Off-season corn yields decreased linearly as the density of *M. sobolifera* plants increased, except in the corn crop in São Miguel do Iguaçu (1) (Figure 4C), which was cultivated with cultivar AS 1633 PRO 2. Estimated grain losses in the crops grown in Marechal C. Rondon, Missal, São Miguel do Iguaçu (2) and Serranópolis do Iguaçu were 70.4; 184.0; 108.8 and 303.7 kg $plant^{-1}$ of *M. sobolifera*, respectively.

In São Miguel do Iguaçu (1), it was impossible to determine the correlation of corn grain yield losses with the densities of *M. sobolifera* plants (Figure 4C). However, the data fit the exponential model in Area 5 in the same municipality (São Miguel do Iguaçu 3, Figure 4E). In this case, there was no yield loss up to the density of 18.6 plants m^{-2}. However, there was a sharp decrease from this point, reaching 34.5% for the highest density assessed in the field (55 plants m^{-2}).

Considering all data for the six areas assessed, it was possible to obtain an adjustment to the quadratic model with statistical significance (p>0.01), despite the low coefficient of determination (Figure 5). Based on the linear coefficient of the model, we observed loss of corn yield for 138.0 kg $plant^{-1}$ of *M. sobolifera*, but as density increased, the competitive weed power decreased. A possible explanation for this phenomenon could be using the data obtained for São Miguel do Iguaçu 1 and 3 (Figures 4C and 4E). In this area, there was low weed interference with corn yields rather than the occurrence of intraspecific competition among *M. sobolifera* plants as density increased. Furthermore, for the other areas examined individually, corn yields decreased linearly as densities of *M. sobolifera* plants increased.

EWT estimates were based on economic criteria (control cost of R$ 257.90 ha^{-1} and grain selling

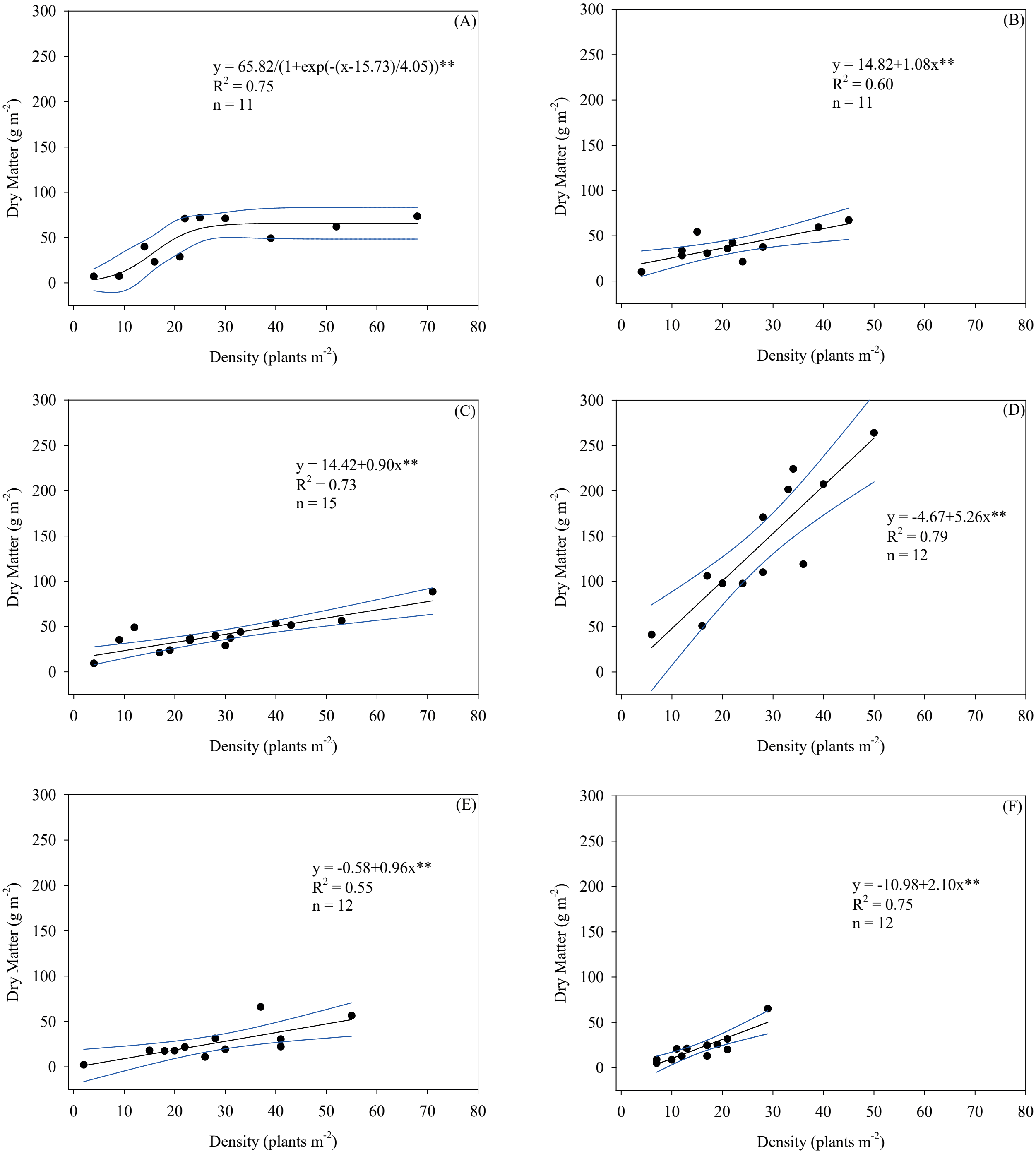

Figure 2. Dry matter of *M. sobolifera* plants relative to the plant densities observed in different corn crops. Area 1: Marechal Cândido Rondon (A), Area 2: Missal (B), Area 3: São Miguel do Iguaçu 1 (C), Area 4: São Miguel do Iguaçu 2 (D), Area 5: São Miguel do Iguaçu 3 (E) and Area 6: Serranópolis do Iguaçu (F). ** Significant at 1% probability by F-test (blue lines indicate the 95% confidence interval).

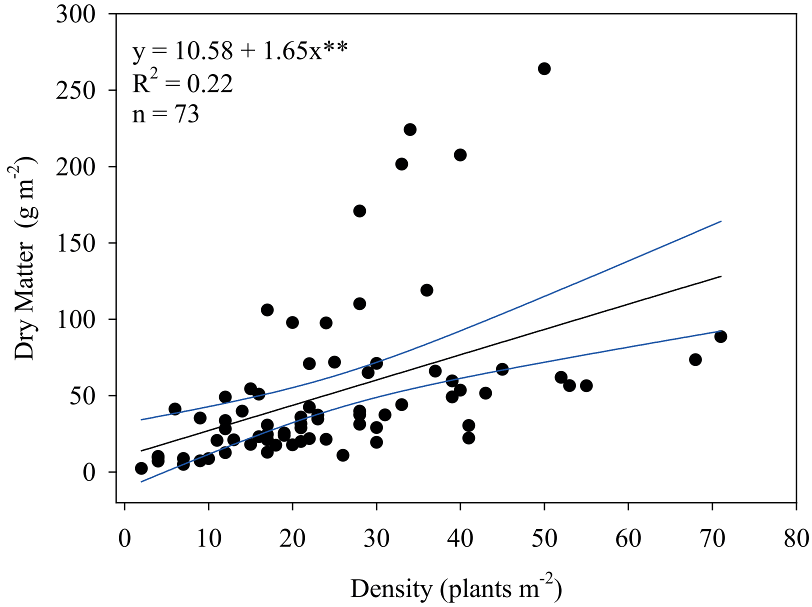

Figure 3. Dry matter of *M. sobolifera* plants according to the densities found in six corn crops cultivated in the western region of the state of Paraná. ** Significant at 1% probability by F-test (blue lines indicate the 95% confidence interval).

price of R$ 0.42 kg^{-1}), representing an acceptable grain yield loss of 614.05 kg ha^{-1}. Therefore, when considering the maximum yields of each hybrid cultivar, the EWT was determined as 8.7; 3.3; 5.6; 41.2 and 2.0 plants m^{-2} of *M. sobolifera* for the corn crops grown in Marechal Cândido Rondon, Missal, São Miguel do Iguaçu (2), São Miguel do Iguaçu (3), Serranópolis do Iguaçu, respectively (Table 1). When considering the mean yields of all areas assessed, the EWT was 4.6 plants m^{-2} of *M. sobolifera*.

In São Miguel do Iguaçu (1), it was not possible to determine the EWT considering that there was no reduction of grain yields (Figure 4C), although there was a linear correlation with the increased rate of biomass accumulation as weed plant densities increased (Figure 3C). On the other hand, São Miguel do Iguaçu (3) exhibited the highest EWT of all areas assessed. These results possibly indicate that the cultivated hybrids 'AS 1633 PRO2' and 'KWS 9006 VT PRO3' (early maturing cultivars) can tolerate coexistence with *M. sobolifera* at densities considered high (41 to 71 plants m^{-2}) (Figures 4C and 4E).

The use of hybrids with higher competitive ability may represent a powerful strategy for the integrated management of weed species that are difficult to control (Carvalho et al., 2011), thus, contributing to reducing the control costs and increasing the producer economic returns. Additionally, in the present study, very early and early maturing corn hybrids were cultivated with reduced spacing (0.5m) between sowing lines, which can explain the greater tolerance of the assessed corn hybrids to coexistence with *M. sobolifera* (EWT of 2.0 to 41.2 plants m^{-2}), compared with the EWT data obtained in crops cultivated with larger spacing (>0.6 m).

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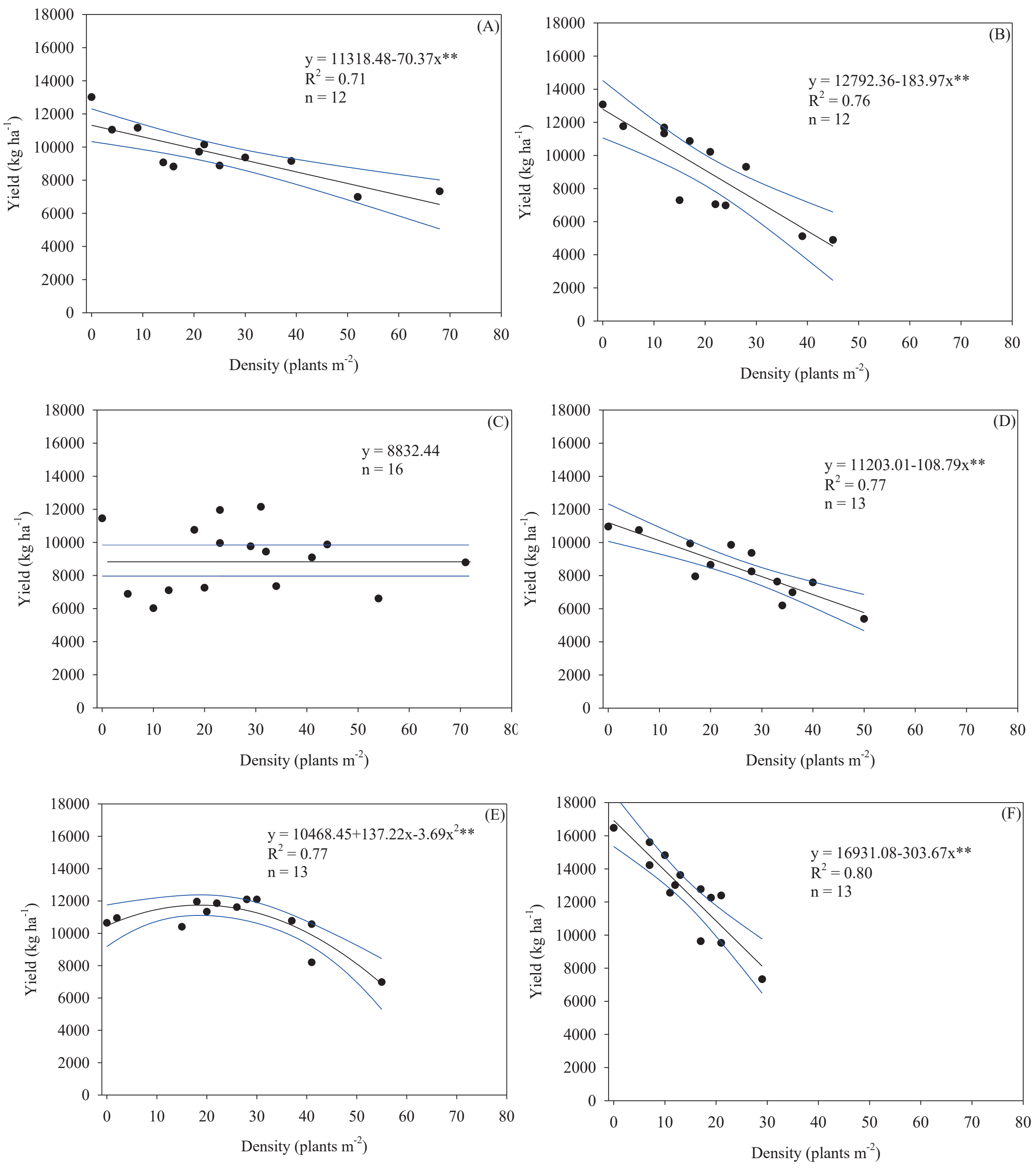

Figure 4. Off-season corn grain yields result from densities of *M. sobolifera* plants obtained in different production areas. Area 1: Marechal Cândido Rondon (A), Area 2: Missal (B), Area 3: São Miguel do Iguaçu 1 (C), Area 4: São Miguel do Iguaçu 2 (D), Area 5: São Miguel do Iguaçu 3 (E) and Area 6: Serranópolis do Iguaçu (F). ** Significant at 1% of probability by the F-test (blue lines indicate the 95% confidence interval).

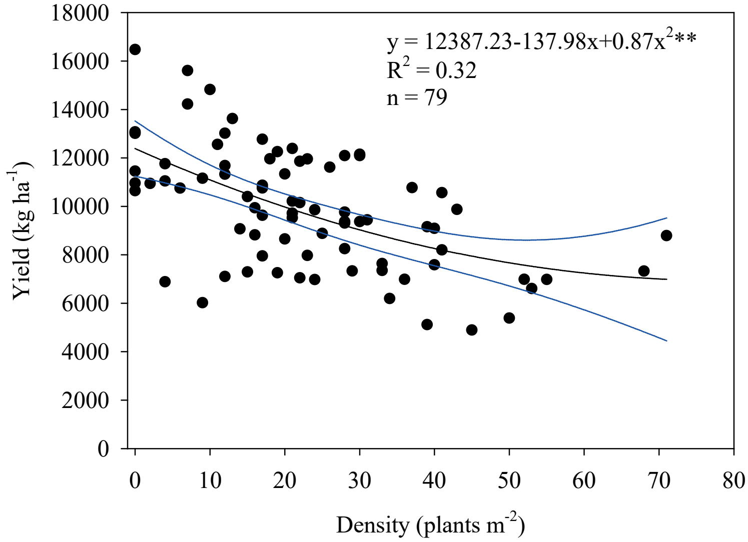

Figure 5. Average grain yields of off-season corn as a function of the densities of *M. sobolifera* plants obtained in six production areas in the western region of Paraná. ** Significant at 1% probability by the F-test (blue lines indicate the 95% confidence interval).

Table 1. Estimated Economic Weed Threshold values of *M. sobolifera* in six off-season corn crops cultivated in western Paraná.

Areas	Off-season hybrid corn cultivars	Maximum yield (kg ha^{-1})	Acceptable yield loss (kg ha^{-1})	EWT** (plants m^{-2})
1. Marechal Cândido Rondon	AS 1777 PRO2	11318.48	614.05	8.7
2. Missal	KWS 9110 VT PRO3	12792.36	614.05	3.3
3. São Miguel do Iguaçu 1	AS 1633 PRO2	8832.44*	614.05	---
4. São Miguel do Iguaçu 2	Syngenta Status Viptera 3	11203.01	614.05	5.6
5. São Miguel do Iguaçu 3	KWS 9006 VT PRO3	10468.45	614.05	41.2
6. Serranópolis do Iguaçu	MG 580 PW	16931.08	614.05	2.0
Mean data for all areas		11892.28	614.05	4.6

*Mean yield. ** Estimated values based on the regression models obtained in Figures 3 and 4.

By comparing the competitive ability of wheat cultivars of different vegetative cycles with *Raphanus raphanistrum*, Tavares et al. (2019) found that the cultivar 'BRS 328' (early maturing cycle) exhibited a higher competitive ability than cultivars 'BRS 177' (medium maturing cycle) and BRS Umbu (late maturing cycle). The advantage of the early maturing cultivars is their fast initial development and leaf area accumulation. As a result, they intercept sunlight more efficiently, thus, reducing the incidence of solar energy to their neighbors and increasing its competitiveness with weed plants (Fleck et al., 2003a).

Balbinot Jr. & Fleck (2005) reported that the

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corn hybrid 'AS-1544' exhibited a higher competitive ability when planted at a spacing of 0.4m between lines, suppressing by 11.4% the accumulation of weed dry matter at 80 days after sowing, when compared to the variety 'Cateto,' and there was an increase of this variable as the spacing between lines increased. The authors also cite that reduced spacing between corn lines is a practice that enhances the ability of the culture to compete with weed plants, especially in genotype, which exhibits a "modern" plant architecture (low plant height and upright leaves).

The corn hybrids 'Pioneer 30F53 YH' and 'Pioneer P1630H' sown at a spacing of 0.5m between lines showed better competitivity with *Urochloa plantaginea* and higher EWTs (1.3 to 5.5 plants m^{-2}) concerning the hybrids 'Syngenta Status VIP 3' and 'Syngenta SX8394 VIP 3' (0.5 to 2.8 plants m^{-2}) (Galon et al., 2019). Vidal et al. (2004) determined EWT between 0.2 and 13.0 plants m^{-2} of *Brachiaria plantaginea* (=*U. plantaginea*) for the corn hybrid 'AG 5011' cultivated at a spacing of 0.8m. In a similar study, Vazin (2012) determined EWT between 0.09 to 0.13 plants m^{-2} pf *Amaranthus retroflexus* for the corn genotype 'SC704' at a spacing of 0.75 m. Thus, the EWT can also vary significantly according to the environmental variables (year), cultivation systems, crop and weed emergence times, competitive ability (weed plant x crop), sowing density of the culture, control efficiency, as well as the economic criteria adopted for each culture (Fleck et al., 2002; Agostinetto et al., 2005; Galon et al., 2007; Vidal et al., 2010; Machado et al., 2015).

In practice, the EWT estimates obtained in the present study can be used in areas where pre-sowing management with desiccant herbicides was carried out and may require post-emergence herbicide applications to keep weed densities at tolerable levels until the end of the crop cycle. However, chemical control of *M. sobolifera* still represents a considerable challenge because this species has natural tolerance to the main herbicides used in corn and soybean cultures (Brighenti et al., 2006), where the use of combined herbicides is necessary in order to improve control effectiveness (Salvalaggio et al., 2017). However, there are few options of effective herbicide combinations to be used at the post-emergence of corn plants to control these weed species.

The use of complex strategies to handle species of difficult control increases costs, influencing the decision of carrying out control or not, since the EWT increases as the control cost increases and grain price decreases. Thus, increases in crop price reduce the impact of weed control costs on the economic return of the culture (Vidal et al., 2004). Another aspect of being considered is that the seeds produced by non-controlled plants at densities below the EWT can enrich the soil seed bank and increase the population density of these species in subsequent crops (Fleck et al., 2003b). However, in the case of *M. sobolifera*, the main form of propagation is vegetative, through rhizomes, and its dispersal capacity, dormancy, and germination are still little known.

According to Kalsing & Vidal (2010), the use of EWT for the management of weed plants is complex due to: (i) interference relations between consuming and producing organisms in the agroecosystem (ii) natural occurrence of multi-specific populations of weed plants in agricultural areas; (iii) non-stability of the biological and economic variables used to estimate EWT; (iv) irrelevance of the parameter for cultures with a low competitive ability against weeds; and (v) medium- and long-term ecological consequences of its use in cultivated areas. Nevertheless, Rizzardi et al. (2003) and Galon et al. (2016) reported that the inherent difficulties and constraints for using EWT as a weed management tool should be a warning. In other words, the use of EWT would only be viable in cropping situations that integrate other weed management practices that could minimize possible adverse effects of non-controlled weed populations, such as crops rotation, adequate plants arrangement, use of more competitive cultivars, and application of efficient herbicide dosages.

Thus, the difficulties currently found in adopting the EWT approach can represent a challenge to research to develop and optimize weed plants management that points to the more rational and economical use of the chemical control measures commonly used with poor or no technical criteria.

Conclusions

M. sobolifera interferes directly in off-season corn yields, causing losses of up to 303.7 kg plant^{-1}. Therefore, considering an acceptable loss of 614.05 kg ha^{-1} in grain yield, EWT estimates ranged from 2.0 to 41.2 plants m^{-2} of *M. sobolifera* coexisting throughout the entire cycle of off-season corn grown in the western region of the state of Paraná. However, corn hybrids have a differential competitive ability relating to the coexistence with *M. sobolifera*, especially 'AS 1633 PRO2' and 'KWS 9006 VT PRO3', the most competitive hybrid cultivars.

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