Received: 22 January 2024 | Accepted: 29 July 2024

DOI: 10.1002/agg2.20563

Agrosystems, Geosciences & Environment OPEN ACCESS

ORIGINAL ARTICLE

Agrosystems

Purple nutsedge management in tomato plasticulture: A study on the effectiveness of preemergence herbicide *S*-metolachlor and its co-application with fertilizer enhancer and chelated iron

Ruby Tiwari[1] | **Anish Sapkota**[2] | **Nathan Boyd**[3] | **Ramdas Kanissery**[1]

[1]Horticultural Sciences Department, Southwest Florida Research and Education Center, University of Florida, Immokalee, Florida, USA

[2]Department of Land, Air and Water Resources, University of California, Davis, California, USA

[3]Horticultural Sciences Department, Gulf Coast Research and Center, University of Florida, Wimauma, Florida, USA

Correspondence
Ramdas Kanissery, Horticultural Sciences Department, Southwest Florida Research and Education Center, University of Florida, 2685 State Road 29 N, Immokalee, FL 34142, USA.
Email: rkanissery@ufl.edu

Assigned to Associate Editor Vanaja Kankarla.

Funding information
USDA FDACS Specialty Crop Block Grant Program; University of Florida, Institute of Food and Agricultural Sciences

Abstract

Purple nutsedge (*Cyperus rotundus* L.) poses a significant challenge to Florida tomato (*Solanum lycopersicum* L.) producers due to its ability to puncture plastic mulch, resilient tubers, and rapid rhizome proliferation. Preemergence herbicides effectively suppress purple nutsedge in tomatoes under plastic mulch. Although the impact of co-application of herbicides with fertilizers has been studied in row crops, its potential in vegetable plasticulture systems remains unexplored. This study aimed to evaluate the effectiveness and crop safety of the preemergence herbicide *S*-metolachlor, both as a standalone treatment and in combination with a fertilizer enhancer or chelated iron in tomato plasticulture. Field trials at the University of Florida's Southwest Florida Research and Education Center, Immokalee, FL, involved applying *S*-metolachlor at the recommended rate of 1 kg a.i. ha^{-1} on raised beds before installing plastic mulch. The herbicide was applied as a blanket spray alone, mixed with fertilizer enhancer, and coated on chelated iron fertilizer. Results indicate that using *S*-metolachlor alone effectively reduced purple nutsedge density compared to the nontreated control in both trials I and II. Combining *S*-metolachlor with fertilizer enhancer or chelated iron resulted in a >30% and 57% reduction in purple nutsedge density, respectively, compared to the nontreated control in trial II. These treatments did not adversely impact chlorophyll content or crop yield ($p > 0.05$) compared to the nontreated control. Notably, tomato yield significantly ($p < 0.05$) decreased with increased purple nutsedge density at 4, 8, and 12 weeks after transplanting. Overall, the results from both trials suggest that using *S*-metolachlor is an effective approach to reduce purple nutsedge infestation in plastic-mulched raised beds without negatively impacting tomato health and productivity.

Abbreviations: SPAD, soil and plant analysis development; WAT, weeks after transplanting.

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
© 2024 The Author(s). *Agrosystems, Geosciences & Environment* published by Wiley Periodicals LLC on behalf of Crop Science Society of America and American Society of Agronomy.

1 | INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a major vegetable crop grown nationwide in the United States. Florida is the top producer of fresh market tomatoes in the United States, contributing approximately $426 million to the state economy (USDA NASS, 2020). Fresh market tomatoes were planted on 22,000 acres of land in Florida in 2022 (National Agricultural Statistics Service, 2022). In 2020, 96% of all tomatoes grown in Florida were sold to the fresh market (USDA NASS, 2020). The peak time for fresh market tomato production in Florida ranges from November to January and April to May (Freeman et al., 2022).

In Florida, approximately 60,000 acres of vegetable crops, primarily consisting of tomatoes, bell peppers, eggplants, strawberries, and watermelons, are currently cultivated using plasticulture techniques (Simmone et al., 2003). Plasticulture is a crop management system that employs fumigation, drip tapes for irrigation, raised beds, and plastic mulch to enhance plant growth, production, and quality by minimizing the risks of weeds, insects, pests, and diseases (Salama & Geyer, 2023; Tiwari et al., 2022). Weed management is a critical production challenge for tomato growers in Florida (Tiwari et al., 2022; Yu et al., 2020). Among many weeds encountered, purple nutsedge (*Cyperus rotundus* L.) is one of the most troublesome weed species in tomato plasticulture production throughout Florida (Holm et al., 1977). Purple nutsedge propagates from the tubers, expands laterally, forming patches, and its pointed shoot tips can penetrate the plastic mulch (Sandhu et al., 2021; Tiwari et al., 2022). Webster et al. (2005) reported the production of 3500 nutsedge shoots in a 22.1 m^{-2} patch from one purple nutsedge tuber under polyethylene mulch within 60 weeks. Nutsedge density and emergence timing affect competition for resources such as water and nutrients and can reduce commercial tomato yield (Bakht et al., 2014; Morales-Payan et al., 2003; Motis et al., 2001). Production location and management practices may alter the effects of nutsedge density on tomato yield (Boyd, 2015; Tiwari et al., 2022). For example, authors reported a 44% yield reduction in tomatoes from 200 shoots m^{-2} purple nutsedge under greenhouse conditions in Gainesville, FL (Morales-Payan et al., 1997). However, according to Boyd (2015), the interference of purple nutsedge in plastic mulched raised beds over a 3-month period had no impact on tomato yield, even at densities of up to 100 shoots m^{-2}.

Nutsedge suppression achieved through bed fumigation under plastic mulch in tomatoes is promising in some studies; however, they often tend to be inconsistent (Santos et al., 2006; Yu et al., 2019). Preemergence herbicides applied on bare soil or on raised beds under polyethylene mulch tend to be an effective tool for nutsedge suppression in tomato production. *S*-Metolachlor {2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*- [(1 S)-2-methoxy-1-mthylethyl] acetamide} (Dual Magnum; Syngenta Crop Protection, LLC) is one of the most widely used preemergence herbicides in many agronomic and horticultural crops (Kanissery et al., 2021; Rachuy & Fennimore, 2022; Tiwari et al., 2021). This soil-applied herbicide is registered for nutsedge control in tomato plasticulture (Devkota et al., 2013; Shaner, 2014). *S*-Metolachlor is a very long-chain fatty acids (VLCFA)-inhibiting herbicide. It impairs cell division and shoot development in susceptible plants (Götz & Böger, 2004; Senseman, 2007). Symptoms include malformed plant seedlings and crinkled leaves with a heart-shaped appearance (Senseman, 2007). Crop injury from this herbicide application has been reported to occur in crop transplants in wet conditions with low organic matter (<2%) soils (Boyd, 2015; Hasanuzzaman et al., 2020). Soil texture, organic matter content, and the presence of microbial population influence the fate of *S*-metolachlor in soil (Kouame et al., 2022; Weber et al., 2003). Sandy soil with low organic matter is less likely to retain the herbicides because of the decreased binding (adsorption) of the herbicides to the soil particles, with a corresponding increase in leaching and loss through volatilization (Curran, 2016; Timilsina et al., 2023).

Major tomato-growing regions in Florida, such as Immokalee, frequently receive heavy rainfall (approximately 1295 mm annually), which causes standing water in the fields (Zhang et al., 2017). Additionally, the soil of Immokalee is very sandy with organic matter content of <1% and pH ranging from 6.5 to 7 (Carson et al., 2014; Gairhe et al., 2021). These factors may cause the preemergence herbicides applied under plastic mulch to easily leach into the crop root zone following heavy rainfall (Rhue & Everett, 1987). It may affect the establishment and early growth of tomato transplants and could adversely impact the efficacy of preemergence herbicides providing inadequate suppression of late-emerging weeds such as purple nutsedge (Fontanelli et al., 2015; Heap, 2014; Pannacci et al., 2017; Rhue &

Core Ideas

- Preemergence herbicide *S*-metolachlor effectively reduced purple nutsedge pressure in plastic mulched tomato beds.
- *S*-Metolachlor application in tomato beds did not result in any adverse impacts on tomato health or productivity.
- Effects of coapplying fertilizer enhancer or chelated iron with *S*-metolachlor were inconsistent between the trials.
- Tomato yield declined with the increase in purple nutsedge density at 4, 8, and 12 weeks after transplanting.

Everett, 1987). Therefore, it is important to incorporate the crop-safe preemergence herbicide application strategies under the plastic mulch.

Fertilizer enhancer Avail (Specialty Fertilizer Products, LLC) is a maleic-itaconic copolymer that enhances phosphorus use efficiency and solubility in soils (Doydora et al., 2017). The product sequesters antagonistic metals near fertilizer granules that possibly prevent plant-uptake of phosphorous from soil (Doydora et al., 2017). Murphy and Sanders (2007) and Summerhays et al. (2017) reported an increase in phosphorous solubility in soil solution from Avail-coated fertilizer through the mid-season when applied to potatoes in Madison, WI. The authors further reported that the addition of fertilizer enhancer (Avail) did not affect maize (*Zea mays* L.) biomass and yields in a hydroponics study, suggesting this product is nontoxic to plants. Fertilizer enhancers can work in tandem with herbicides to boost their effectiveness. For example, specific enhancers like Avail have the ability to alter soil pH (Hopkins et al., 2018). This pH modification is crucial because the performance and longevity of certain herbicides, like *S*-metolachlor, are influenced by soil pH (Filimon et al., 2021). By adjusting the pH, these enhancers can enhance the weed control efficiency of such herbicides. Moreover, these enhancers also improve the availability of nutrients in the soil, which in turn helps crops better withstand abiotic stresses, including the potential toxic effects of herbicides (Kumari et al., 2022). However, despite these advantages in improving the efficacy and safety of herbicides for crops, the full potential of these materials has not been extensively studied or utilized.

Iron is an important micronutrient and fertilizer the plants require and is often added as iron chelates in crop production systems (Álvarez-Fernández et al., 1996; Lindsay, 1984). Greenhouse studies have indicated the use of chelated iron fertilization to increase the tomato fruit weight without possessing any visual disturbances in plant growth and development (El-Desouky et al., 2021). Previous studies have evaluated the application of an iron amendment concurrently with the herbicide in alleviating herbicide toxicity in soybeans (Franzen et al., 2003). The type of chelating agent, the specific surface area of the soil, lime content, and the ability of a plant to take up the micronutrient define the overall efficacy of a chelate as an iron fertilizer (Assaad & Awad, 1981; Lucena et al., 1987). Chelated iron increases the solubility and retention of micronutrients that are naturally available or applied to soils (Lobartini & Orioli, 1988). Chelating agents are beneficial in enhancing iron availability to plants, provided they possess adequate stability to retain iron in chemical environment of soils. The equilibrium dynamics of chemicals within the soil–plant root interface ultimately control the solubility of iron and its availability to the plants (Lindsay & Schwab, 1982). Different forms of iron fertilizers, including chelated iron, have been investigated to assess their nutritional value for various crops like soybeans and rice (Caliskan et al., 2008; He et al., 2013). Additionally, there is a significant potential in agriculture for iron chelates as multifunctional materials, not only for replenishing plant nutrients but also for delivering pesticides (Shan et al., 2020). To date, there have been no studies, best to our knowledge, examining the co-application of preemergence herbicides with fertilizers, such as chelated iron, to enhance herbicide effectiveness and ensure the safety of tomato crops cultivated using plasticulture methods.

Combining herbicides with fertilizers has proven to be a cost-effective approach in various cropping systems (Geier & Stahlman, 2009; Klein, 2008). For instance, the practice of simultaneously applying herbicide such as imazamox (a postemergence broadleaf herbicide) at 35 g ha^{-1} and nitrogen fertilizer at different concentrations such as (1%, 5%, 10%, 25%, 50%, or 100% v/v) at the fall and spring timings, known as the "weed-and-feed approach," is commonly employed in states like Nebraska and Kansas for winter wheat (*Triticum aestivum* L.) (Geier & Stahlman, 2009; Klein, 2008) and reported to be effective in controlling 66%–73% of the weed population (Geier & Stahlman, 2009). Nitrogen fertilizers have been more frequently added to the spray solution, even as an adjuvant to increase the herbicide performance (Curran et al., 1999). Furthermore, in a laboratory experiment (unpublished) conducted at the Southwest Florida Research and Education Center (SWFREC) in Immokalee, FL, it was observed that fertilizers, including chelated iron, exhibited promise as potential slow-release agents for *S*-metolachlor. However, this approach's effectiveness in horticultural crops, particularly in Florida's sandy soils, remains largely unexplored. Limited scientific research has investigated the use of preemergence herbicides in combination with fertilizers and fertilizer enhancers to enhance crop growth and achieve effective long-term control of purple nutsedge in Florida's tomato plasticulture production. Therefore, this study aimed to address this research gap by evaluating the effectiveness of preemergence herbicide *S*-metolachlor alone and in combination with fertilizer enhancer and chelated iron on raised beds under plastic mulch. The focus was on assessing the impact of this co-application on purple nutsedge control, crop vigor, chlorophyll content, tomato biomass, and yield. Inadequate weed control methods can have a detrimental impact on the growth and yield of tomato crops (Chaudhari et al., 2016). With the increasing popularity of fresh market tomato plasticulture production in Florida, it is crucial to assess how weed density, crop vigor, and chlorophyll levels influence tomato productivity throughout the growing seasons. Therefore, the present research also sought to establish a correlation between the density of purple nutsedge, crop vigor metrics, and chlorophyll levels with tomato productivity in plasticulture production.

2 | MATERIALS AND METHODS

Two field trials were carried out at the SWFREC (latitude: 26°28′7″ N, longitude: 81°26′22″ W), Immokalee, FL. Trial I took place in the spring season, whereas trial II occurred during the fall season of 2021. Typically, there is only a minimal variation in the weather in South Florida across the spring and fall seasons (Sandhu et al., 2022). The soil type at the research center was classified as Spodosol fine sand with a pH of 7 and 0.4% organic matter (websurvey.sc.egov.usda.gov).

To ensure adequate soil moisture and tilth for bed formation, the field was cultivated and irrigated before bed preparation. All the beds were then shaped and pressed by using the CASE IH Farmall Compact C Series II Tractor. Treatments included *S*-metolachlor at the labeled rate of 1 kg a.i. ha^{-1} alone or in combination with fertilizer enhancer (Avail) (1.86 L ha^{-1}) or chelated iron (1401.20 kg ha^{-1}). The rate of preemergence herbicide *S*-metolachlor was chosen based on the growers' standard practice (Tiwari et al., 2022). Additionally, a nontreated control was included. The experimental design was a randomized complete block with five replications. The individual plot size was 3-m long with a 0.75-m wide raised bed. Preemergence *S*-metolachlor alone or in combination with fertilizer enhancer was sprayed on the top of the bed with two passes with 121.5 L ha^{-1} of water using a backpack sprayer equipped with a single ATR 80 nozzle (Teejet Technologies) with 0.24 MPa of pressure. *S*-Metolachlor and chelated iron were combined and thoroughly mixed using a Klutch Portable Electric Cement Mixer in a 4.25 cubic feet drum (Northern Tool and Equipment Company, Inc.). *S*-Metolachlor with chelated iron coating was hand-applied, covering the entire area on the top of the bed. Treatments were applied on March 3, 2021 for the trial I and September 30, 2021 for the trial II. Two rows of drip tape, sourced from Jain Irrigation Inc., were buried at a shallow depth just below the soil surface of each bed. The drip tape had a flow rate of 0.95 L min^{-1} 30 m^{-1}. Following treatment, the beds were immediately covered with the black and white totally impermeable film (Berry Plastic Corp.). Di Gioia et al. (2016) reported a lack of nematode pressure in the research location; hence, the beds were not fumigated. Based on the soil test results conducted by the Waters Lab (Waters Agricultural Laboratories, Inc.), the trial site exhibited an average iron content of 26.3 ± 3.48 kg ha^{-1}, indicating an adequate presence of iron in the soil. Tomato variety (HM 1823) was transplanted with 20 cm spacing between the plants in a single row, and each plot consisted of seven tomato plants. Variety HM 1823 was chosen because it is the early-maturing and widely used variety in the area (Freeman et al., 2022). Crop transplanting was done at 2 weeks after treatment application in trial I and 4 weeks after treatment application in trial II. The delay in trial II between applying treatments and transplanting occurred because we needed to re-transplant the tomatoes in every plot. This was necessary to address the issue of poorly performing transplants that were initially planted. In Florida, tomatoes are usually transplanted into raised beds in plasticulture systems about 2 weeks to 1 month after applying preemergence herbicides (Boyd, 2015; Yu et al., 2020). Tomato transplants were fertilized through band application. In this case, a narrow strip of fertilizers was placed at the recommended rates of 226-170-253 kg ha^{-1} N (nitrogen), P_2O_5 (phosphorus), and K_2O (potassium) (Hochmuth & Hanlon, 2011) below the soil surface during the bedding by using the CASE IH Farmall Compact C Series II Tractor. The plots were irrigated following industry standards (Freeman et al., 2016).

2.1 | Data collection

The number of purple nutsedge shoots that punctured the plastic mulch was counted from every plot at 4, 8, and 12 weeks after transplanting (WAT). The timing for the sampling intervals, set at every 4 weeks, was determined based on inputs from experienced growers familiar with tomato production in raised bed plasticulture systems, as well as references from relevant literature (Boyd, 2015; Boyd & Reed, 2016).

Tomato crop vigor was visually estimated at 4 and 8 WAT, which are the vegetative and reproductive (flowering) stages of the crop. The crop vigor was recorded on a scale ranging from 0 to 10, where 0 indicates completely desiccated tomato plants, and 10 indicates healthy tomato crops (Boyd, 2015). Chlorosis, necrosis, stunting, and leaf deformation were surveyed according to the visual injury estimates.

Chlorophyll content was determined by choosing the leaves of three different tomato plants (one reading each) from the middle of every plot (three readings) using a non-destructive and optical technique, soil and plant analysis development (SPAD) 502 Chlorophyll Meter (Konica-Minolta Corporation). Before measurement, the SPAD-502 meter was calibrated using the reading checker supplied by the manufacturer (Güler & Büyük, 2007; Jiang et al., 2017). The chlorophyll content data were recorded on a clear sunny day at 4 and 8 WAT.

Tomato fruits were hand-harvested once they reached the breaker stage on May 31, 2021, and June 9, 2021 for trial I and January 13 and January 31, 2022 for trial II following the industry standards. Fruits were graded as small (<5.5-cm diameter), medium (5.5 cm < diameter < 6.5 cm), large (6.5 cm < diameter < 7 cm), or extra-large (7-cm diameter) to record the total numbers of the harvested fruits (Boyd, 2015). All the graded fruits were then combined and weighed to record the marketable yield.

The aboveground biomass of tomatoes was hand-harvested by using FELCO F-2 Classic Manual Hand Pruner (Pygar USA, Inc.) by selecting three representative plants from the center of each plot on June 10, 2021, for trial I, and February 1, 2022, for trial II. Harvested plant samples were air-dried at 65°C for 2 days to record the dry biomass.

TABLE 1 Monthly total rainfall and mean air temperature data for trials I and II during tomato growing seasons. Data were obtained from the Florida Automated Weather Network (FAWN) located at the University of Florida/IFAS-Southwest Florida Research and Education Center at Immokalee, FL.

	Total rainfall		Mean temperature	
Months	Trial I (mm)	Trial II (mm)	Trial I (˚C)	Trial II (˚C)
March 2021	17	–	21	–
April 2021	57	–	23	–
May 2021	31	–	25	–
June 2021	119	–	26	–
September 2021	–	228	–	26
October 2021	–	60	–	25
November 2021	–	172	–	20
December 2021	–	4	–	20
January 2022	–	26	–	17
Total/mean[a]	224	490	23.8	20.5

[a]Total is presented for rainfall, and the mean is shown for temperature.

TABLE 2 Analysis of variance for the effects of trials, time point, treatments, and the interaction between trials and time point, trials and treatments, time point and treatments, and trials, time point, and treatments on purple nutsedge density, crop vigor, and chlorophyll content at the Southwest Florida Research and Education Center, Immokalee, FL.

Source of variation	Purple nutsedge density	Crop vigor	Chlorophyll content
	p value	———*p* value———	
Trials	<0.001	<0.001	0.01
Time point	0.29	0.82	<0.001
Treatments	<0.001	<0.001	0.04
Trials × time point	0.91	0.63	0.01
Trials × treatments	<0.001	0.03	0.03
Time point × treatments	0.97	0.71	0.57
Trials × time point × treatments	0.99	0.68	0.20

Note: Data were combined at different time points for trial I and trial II.

2.2 | Statistical analysis

The planting was delayed in trial II due to poor growth of tomato transplants. This difference in the time gap between treatment application and transplanting, along with variability in rainfall and temperature (Table 1), likely contributed to significant interactions ($p < 0.05$) across variables between the two trials (Table 2). As a result, the data for trial I and trial II were analyzed and presented separately.

Data were subjected to the analysis of variance using the R version 4.2.3 (http://www.rproject.org/). Normality and homogeneity of variance were checked before analyzing data. Data were normalized with square root transformation when needed. Weed management treatments were considered as the fixed factors, whereas the replications were considered the random factors. Means were separated using the Tukey's honestly significant difference test at $\alpha = 0.05$. Data for purple nutsedge density, tomato crop vigor, and chlorophyll content recorded at multiple time points were analyzed using the repeated statement.

A secondary analysis was also performed where treatment means in trials I and II were used to determine the relationship of crop yield as the response variable and purple nutsedge density, tomato crop vigor, and chlorophyll content (SPAD index) as predictor variables. A simple linear regression analysis ($y = \alpha + \beta x$) determined the relationship where y = response variable (i.e., tomato yield), α = intercept, β = slope, and x = predictor variables (e.g., weed density, crop vigor, and SPAD index). The data analysis tool in Microsoft Excel 2016 with the regression option was used to perform this regression statistics, specifically for determining the significance of the relationship and generating the slope and intercept coefficients required for the linear regression equation. The significance was determined at $p < 0.05$.

3 | RESULTS

This study highlighted a noticeable difference in purple nutsedge weed pressure between the two experimental trials (Table 2). In trial I, the application of the preemergence herbicide *S*-metolachlor alone resulted in a substantial 95% reduction in purple nutsedge density compared to the nontreated control. Also, in trial II, *S*-metolachlor treatment led to a 56% decrease in purple nutsedge density compared to the nontreated control (Table 3). When *S*-metolachlor was coapplied with a fertilizer enhancer in trial I, there was no statistically significant impact ($p > 0.05$) on purple nutsedge density compared to the nontreated control, as shown in Table 3. However, in trial II, a noticeable reduction in nutsedge density (>30%) was observed in the beds treated with *S*-metolachlor combined with a fertilizer enhancer. Similarly, the application of *S*-metolachlor and chelated iron resulted in a 57% reduction in purple nutsedge density compared to the nontreated control, but this trend was only evident in trial II.

During trial I, *S*-metolachlor alone, preemergence *S*-metolachlor + fertilizer enhancer mix, and *S*-metolachlor + chelated iron did not impact the crop vigor at 4 WAT; however, they showed a significant impact ($p = 0.04$) on the crop vigor compared to the nontreated control at 8 WAT (Table 4). In trial II, there were no notable effects on crop vigor both at 4 and 8 WAT in any of the treatments when compared to the nontreated control (Table 4).

TABLE 3 Purple nutsedge counts in plastic-mulched beds that received different treatments during the trials[a].

Treatments	Rates	Mean purple nutsedge density[b]	
		Trial I (No./3m^2)	Trial II (No./3m^2)
Nontreated control	–	0.92ab[c]	11.67a
S-Metolachlor	1 kg a.i. ha^{-1}	0.04c	5.13b
S-Metolachlor + fertilizer enhancer	(1 kg a.i. ha^{-1} + 1.86 L ha^{-1})	0.28bc	7.60b
S-Metolachlor + chelated iron	(1 kg a.i. ha^{-1} + 1401.20 kg ha^{-1})	2.32a	4.93b
p value	–	<0.001	<0.001

[a]Data shown is from the average of the various time points across two different trials.
[b]Number of observations (n) = 5.
[c]Means followed by the different letters differ significantly at $\alpha = 0.05$ based on Tukey's honestly significant difference (HSD) test.

Chlorophyll content was not affected ($p > 0.05$) by any of the treatments at 4 and 8 WAT when compared to the nontreated control both in trials I and II (Table 5). The mean chlorophyll content (SPAD index) ranged from 47.53 to 61.16 for trial I and from 52.54 to 56.58 in trial II (Table 5).

In trial I, the combination of *S*-metolachlor and chelated iron resulted in significantly lower crop biomass (84.4 g plant^{-1}) compared to the nontreated control (126.7 g plant^{-1}), as shown in Figure 1. However, this trend was not consistently observed in trial II, where none of the treatments significantly differed from the nontreated control in terms of crop biomass (Figure 1).

Moreover, after analyzing the harvest data in both trials I and II, it was observed that the treatments had no impact on tomato fruit yields (Figure 2).

There was a significant decline in tomato yield as the number of purple nutsedge increased at 4 WAT ($R^2 = 0.75$, $y = -171.74x + 3051.2$), 8 WAT ($R^2 = 0.72$, $y = -161.41x + 3156.5$), and 12 WAT ($R^2 = 0.69$, $y = -151.49x + 3169.7$) (Figure 3A). Tomato crop vigor at 4 WAT ($R^2 = 0.87$, $y = 666.39x - 3450.7$) and 8 WAT ($R^2 = 0.82$, $y = 744.78x - 4168.4$) was strongly correlated with the yield (Figure 3B). The chlorophyll content collected at 4 WAT did not strongly correlate with the tomato yield; however, the chlorophyll content at 8 WAT had a strong and positive correlation with the crop yield ($R^2 = 0.84$, $y = 231.97x - 10{,}904$) (Figure 3C).

4 | DISCUSSION

Ensuring effective weed management is vital for achieving high-quality fruit production (Zargar et al., 2019; Zimdahl, 2004), and failure to do so can result in significant yield losses in tomatoes (Buckelew et al., 2006; Garvey et al., 2013). In this study, using *S*-metolachlor by itself effectively controlled purple nutsedge in both trials. Prior reports also corroborate this finding. For instance, *S*-metolachlor applied as a pre-emergence herbicide provided 60%–80% control for yellow nutsedge at 4–6 weeks after treatment application; however, the results for purple nutsedge were markedly reduced and erratic (Bangarwa et al., 2009; Boyd, 2015). Miller and Dittmar (2014) investigated that a high density of nutsedge (>100 shoots m^{-2}) was difficult to control in plastic mulch bell pepper (*Capsicum annuum* L.) when relying on an application of *S*-metolachlor alone. In another study conducted, it was observed that the pre-treatment application of *S*-metolachlor did not lead to a reduction in purple nutsedge density compared to the weedy control group (Bayat et al., 2021).

Also, in our study, the co-application of *S*-metolachlor with fertilizer enhancer or chelated iron fertilizer only led to an improvement in suppressing purple nutsedge pressure in one trial. Multiple field studies have consistently reported variations in the control of purple nutsedge when utilizing preemergence applications of *S*-metolachlor across different locations and time periods. *S*-Metolachlor has moderate water solubility, which increases its potential to move within the soil profile (Caracciolo et al., 2005; Shaner, 2014). Its mobility in soil is inversely related to adsorption, making it likely to leach, especially in sandy soils with low organic matter (Obrigawitch et al., 1981). In our study, it is also probable that photodegradation of *S*-metolachlor occurred post-application. These factors could have caused rapid initial dissipation, reducing its effectiveness in suppressing the growth of purple nutsedge weeds (Braverman et al., 1986; Fernandez et al., 2020; Grichar et al., 1992). In contrast, purple nutsedge tubers have a rapid reproductive capacity and can remain viable in the soil for multiple seasons. This characteristic contributes to the unpredictable and irregular emergence of these weeds (Webster et al., 2005). In the present study, the density of purple nutsedge was considerably lower in trial I than in trial II (Table 3). A study conducted by Boyd (2015) revealed a significantly lower density of purple nutsedge in the spring season compared to the fall season. The study also highlighted that the variations in efficacy between the two seasons could be a contributing factor to the observed variability in purple nutsedge density.

The plots treated with *S*-metolachlor, *S*-metolachlor + fertilizer enhancer, and *S*-metolachlor + chelated iron had a significant reduction in tomato crop vigor at 8 WAT in trial I (Table 4). It could be because the tomato crop experienced slightly high temperatures during the flowering stage (May 2021), as shown in Table 1. At high temperatures, photoassimilates (energy-storing compounds) accumulation in fruits is increased, possibly affecting the growth and vigor of tomato plants. Additionally, studies have indicated that elevated temperatures in the growing environment can influence

TABLE 4 Visual assessment of the crop vigor of tomato plants (from 0 to 10, where 0 is a dead plant and 10 is a perfect healthy plant) in response to different treatments during the trials[a].

Treatments	Rates	Crop vigor[b]			
		Trial I		Trial II	
		4 WAT[a]	8 WAT	4 WAT	8 WAT
		Visual rating			
Nontreated control	–	10	10a[c]	8	8ab
S-Metolachlor	1 kg a.i. ha^{-1}	10	9b	9	9a
S-Metolachlor + fertilizer enhancer	(1 kg a.i. ha^{-1} + 1.86 L ha^{-1})	10	9b	8	9a
S-Metolachlor + chelated iron	(1 kg a.i. ha^{-1} + 1401.20 kg ha^{-1})	9	9b	7	7b
p value	–	0.41	0.04	0.15	0.02

[a]Observations made at 4 WAT (weeks after transplanting) and 8 WAT during trials I and II.
[b]Number of observations (n) = 5.
[c]Means followed by the different letters differ significantly at $\alpha = 0.05$ based on Tukey's honestly significant difference (HSD) test.

TABLE 5 Average chlorophyll content measured in the leaves of tomato plants grown in plastic mulched raised beds that received different treatments during the trials[a].

Treatments	Rates	Mean chlorophyll content[b]			
		Trial I		Trial II	
		4 WAT[a]	8 WAT	4 WAT	8 WAT
		SPAD index			
Nontreated control	–	55.18	61.16	56.54	54.52
S-Metolachlor	1 kg a.i. ha^{-1}	56.20	59.68	52.70	53.72
S-Metolachlor + fertilizer enhancer	(1 kg a.i. ha^{-1} + 1.86 L ha^{-1})	57.02	60.42	52.54	56.58
S-Metolachlor + chelated iron	(1 kg a.i. ha^{-1} + 1401.20 kg ha^{-1})	47.53	57.21	54.30	55.04
p value	–	0.07	0.08	0.21	0.48

Abbreviation: SPAD, soil and plant analysis development.
[a]Observations made at 4 WAT (weeks after transplanting) and 8 WAT during trials I and II.
[b]Number of observations (n) = 5.

water distribution within plants and alter cellular structures, impacting fruit development and overall crop vigor (Collins et al., 2022; Wilson, 1985). High root zone temperatures can also affect water and mineral uptake, assimilate partitioning, root respiration, and ultimately plant growth (Díaz-Pérez et al., 2005). A previous study has reported that the excess iron elements present in the growth medium (soil) could be adsorbed by the plant, which is lethal to the plant cells (Fageria et al., 1990). Iron can be toxic to plants on poorly drained acidic soils, which are already rich in iron (Fageria et al., 1990). When excess Fe is present in the growth medium, it may inhibit the uptake, transport, and utilization of many other nutrients and induce nutritional deficiency, ultimately affecting plants' growth (Barbosa Filho et al., 1983).

The chlorophyll content serves as a significant indicator of leaf photosynthesis ability, overall physiological performance, and potential crop stress (Monje & Bugbee, 1992; Peng et al., 1993). None of the treatments had any significant impact on chlorophyll content when compared to the nontreated control for any of the trials (Table 5). A comparable study conducted in Balm, FL, found that applying *S*-metolachlor under the plastic mulch prior to tomato transplanting did not cause any harm to the growth of the plants (Boyd, 2015).

The co-application of *S*-metolachlor with chelated iron had an impact on crop biomass, specifically during trial I (Figure 1). Similarly, this treatment also resulted in reduced crop vigor during trial I, suggesting that this effect might have contributed to the observed impact on biomass as well.

The present study reported no effect on the yield of tomatoes ($p > 0.05$) with *S*-metolachlor alone when co-applied with fertilizer and chelated iron for both trials (Figure 2). There are similar reports indicating that the preemergence application of *S*-metolachlor in plasticulture systems does not have a significant impact on tomato yield (Boyd, 2015). A prior study conducted by Rhue and Everett (1987) similarly found no observable effects on tomato yields in subsequent years when high rates of phosphorus were applied to Immokalee sand. The present study demonstrated a numerical increase in tomato fruit yields during trial I than trial II

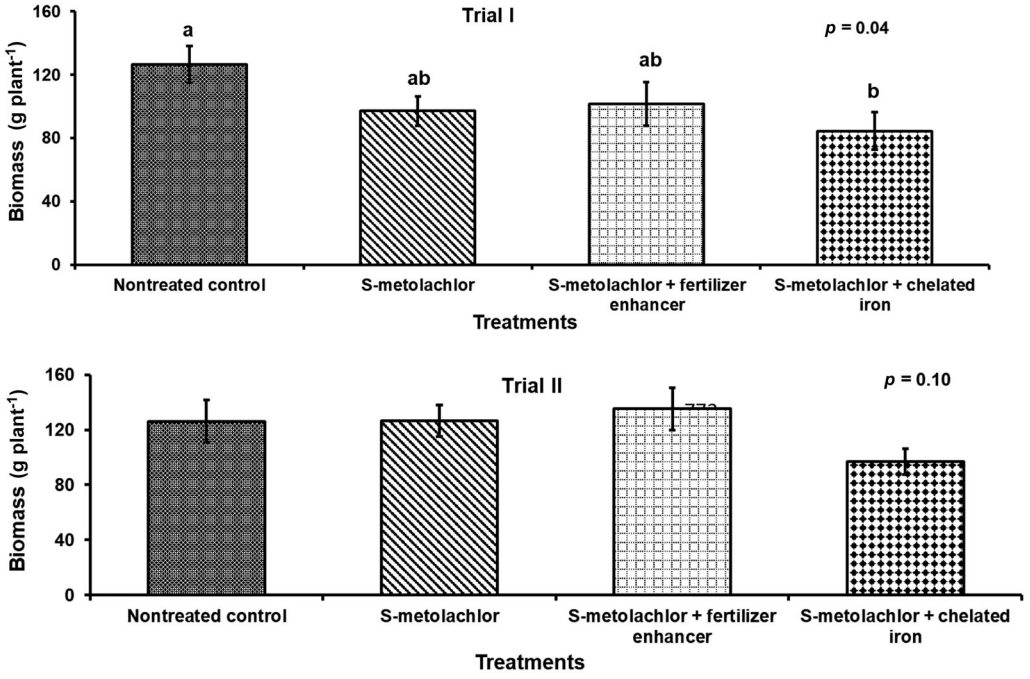


FIGURE 1 Effects of treatments (nontreated control), *S*-metolachlor (1 kg a.i. ha^{-1}), *S*-metolachlor + fertilizer enhancer (1 kg a.i. ha^{-1} + 1.86 L ha^{-1}), and *S*-metolachlor + chelated iron (1 kg a.i. ha^{-1} + 1401.20 kg ha^{-1}) on tomato biomass in trials I and II. Error bars represent the standard errors of the means. *p* values are shown, and if letters are present, bars with the different letters differ significantly at $\alpha = 0.05$ based on Tukey's honestly significant difference (HSD) test.

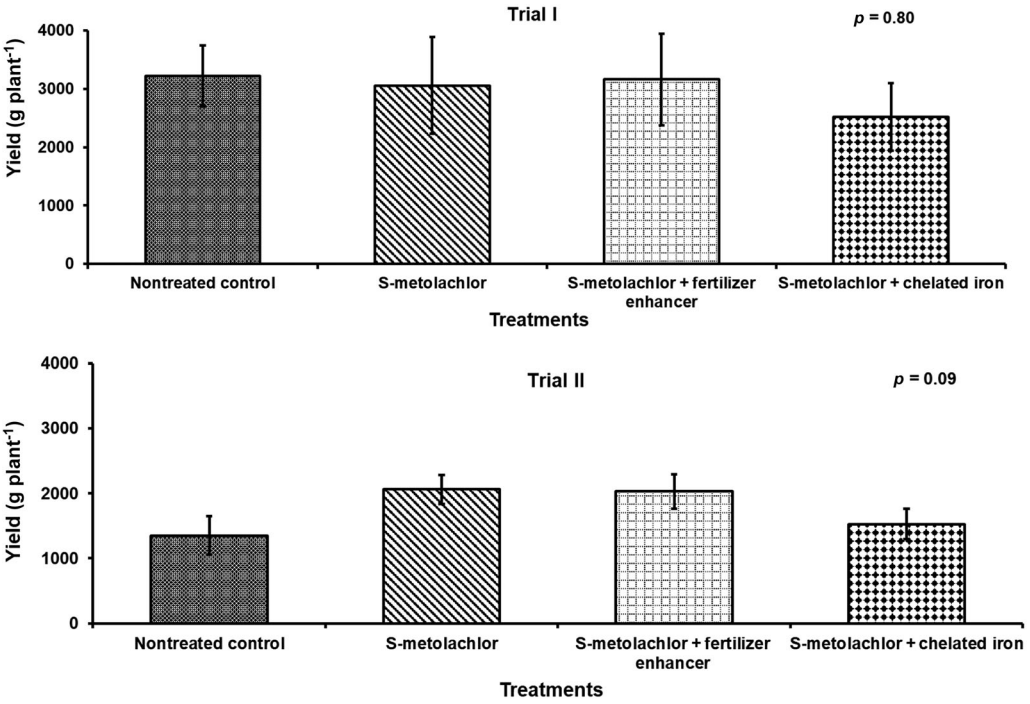


FIGURE 2 Effects of treatments (nontreated control), *S*-metolachlor (1 kg a.i. ha^{-1}), *S*-metolachlor + fertilizer enhancer (1 kg a.i. ha^{-1} + 1.86 L ha^{-1}), and *S*-metolachlor + chelated iron (1 kg a.i. ha^{-1} + 1401.20 kg ha^{-1}) on marketable tomato yields in trials I and II. Error bars represent the standard errors of the means. *p* values are shown, and if letters are present, bars with the different letters differ significantly at $\alpha = 0.05$ based on Tukey's honestly significant difference (HSD) test.

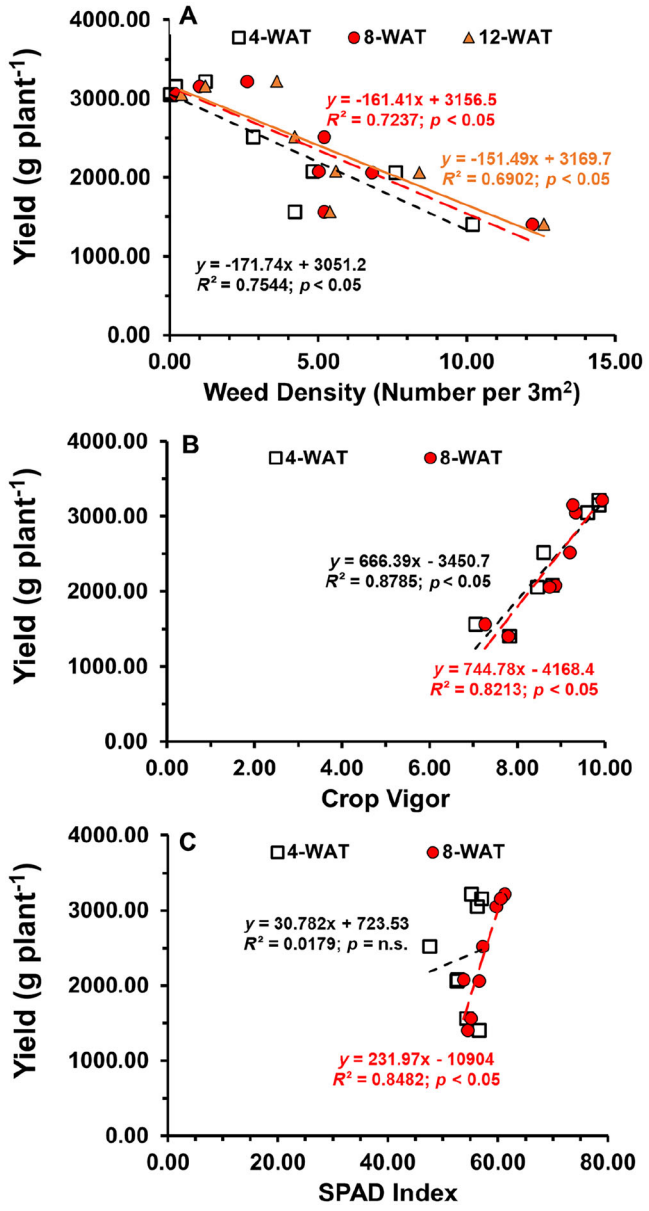


FIGURE 3 Relationship between the response variable (tomato yield) and predictor variables. (A) Purple nutsedge density, (B) crop vigor, and (C) soil and plant analysis development (SPAD) index. In the figure, WAT = weeks after transplanting, SPAD index measures the chlorophyll content, n.s. = non-significant at $p < 0.05$. The open square represents 4 WAT, closed red circle represents 8 WAT, and closed triangle represents 12 WAT. Mean values for each treatment from trials I and II were used to establish the relationship.

(Figure 2). This variation in tomato yield between the two seasons could possibly be due to the differences in climate and field conditions at the crop transplanting (Table 1) and the difference in the time between treatment application and the transplanting of tomato seedlings. In line with previous research by Chaudhari et al. (2016) and Garvey et al. (2013), it was found that the critical weed-free period for tomatoes typically falls within 3–6 WAT. Considering this, it can be inferred from the current study that the emergence of purple nutsedge beyond this critical weed-free period might not pose a significant competitive threat leading to substantial yield reductions in tomatoes.

The yield decreased with the increase in purple nutsedge density at 4, 8, and 8 WAT (Figure 3A). Morales-Payen et al. (1997) found that as the density of purple nutsedge increased up to 200 plants m^{-2}, there was a linear reduction in tomato fruit yield. This suggests a clear negative impact of increasing purple nutsedge density on tomato crop productivity. There was an increase in tomato yield with the increase in crop vigor and health at 4 and 8 WAT (Figure 3B,C).

Although there was some level of suppression observed in purple nutsedge populations, a notable number of nutsedge plants managed to survive until the end of both trials. This survival of purple nutsedge plants can pose challenges for future weed management practices, particularly when relying only on a single herbicide such as *S*-metolachlor. It highlights the importance of incorporating multiple modes of action to effectively control and prevent the development of herbicide-resistant weeds. Hence, the combination of preemergence herbicides with diverse modes of action can effectively deter the development of herbicide-resistant weeds and enhance long-term weed management strategies (Galon et al., 2018; Zargar et al., 2019).

5 | CONCLUSIONS AND FUTURE DIRECTIONS

S-Metolachlor is a commonly used preemergence herbicide to control weeds like purple nutsedge in tomato plasticulture. However, it poses the risk of leaching from the weed seed germination zone to the root zone of the establishing tomato crop, particularly in Florida's sandy soil regions. This leaching can lead to inadequate weed suppression, reduced crop vigor, and hindered crop establishment. This study explored the weed control effectiveness and crop safety of applying *S*-metolachlor in tomato beds covered with plastic mulch, by itself and in combination with a fertilizer enhancer and chelated fertilizer. Our findings from two trials indicate that applying *S*-metolachlor alone as a blanket spray on the raised tomato beds before installing the plastic mulch effectively controlled purple nutsedge without impacting the crop health or yield. Combining this herbicide with a fertilizer enhancer or chelated iron also reduced purple nutsedge pressure; however, only in one of the trials. Nonetheless, this approach may be used under plastic mulch without compromising the overall yield. To manage purple nutsedge effectively, it is advisable to integrate a postemergence herbicide program into existing weed management practices. In the future, exploring the fate and behavior of herbicide treatments under plastic mulch using analytical techniques would be beneficial,

given the diverse soils across different regions of Florida's vegetable plasticulture systems. Additionally, investigating different herbicide application rates could provide valuable insights. Overall, this research could offer an initial understanding of the effectiveness of *S*-metolachlor alone or in combination with fertilizer additives or slow-release fertilizers and their potential impact on weed suppression, crop establishment, and growth.

AUTHOR CONTRIBUTIONS

Ruby Tiwari: Conceptualization; data curation; formal analysis; investigation; methodology; software; writing—original draft; writing—review and editing. **Anish Sapkota**: Data curation; software; validation; writing—review and editing. **Nathan Boyd**: Conceptualization; supervision; writing—review and editing. **Ramdas Kanissery**: Conceptualization; funding acquisition; methodology; project administration; resources; supervision; validation; writing—review and editing.

ACKNOWLEDGMENTS

The authors thank Robert Riefer and Shea Teems for their assistance with fieldwork and data collection. This research was funded by the Florida Department of Agriculture & Consumer Services (FDACS)-Specialty Crop Block Grant (SCBG) and the University of Florida.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Ramdas Kanissery https://orcid.org/0000-0003-3161-3865

REFERENCES

Álvarez-Fernández, A., Gárate, A., Juárez, M., & Lucena, J. J. (1996). Tomato acquisition of iron from iron chelates in a calcareous sandy substrate. *Journal of Plant Nutrition*, *19*(8–9), 1279–1293. https://doi.org/10.1080/01904169609365198

Assaad, F. F., & Awad, F. (1981). The stability of iron chelates in calcareous soils. *Zeitschrift für Pflanzenernährung und Bodenkunde*, *144*(1), 77–86. https://doi.org/10.1002/jpln.19811440110

Bakht, T., Khan, I. A., Marwat, K. B., & Hussain, Z. (2014). Integration of row spacing, mulching and herbicides on weed management in tomato. *Pakistan Journal of Botany*, *46*(2), 543–547.

Bangarwa, S. K., Norsworthy, J. K., & Gbur, E. E. (2009). Cover crop and herbicide combinations for weed control in polyethylene-mulched bell pepper. *HortTechnology*, *19*(2), 405–410. https://doi.org/10.21273/HORTSCI.19.2.405

Barbosa Filho, M. P., Fageria, M. P., & Stone, L. F. (1983). Water management and liming in relation to grain yield and iron toxicity in rice. *Pesquisa Agropecuaria Brasileira*, *18*(8), 903–910.

Bayat, M., Zargar, M., Pakina, E., Lyashko, M., & Chauhan, B. S. (2021). Impact of PRE-and POST herbicide on purple nut sedge (*Cyperus rotundus* L.) control and plasticulture tomato yields. *Chilean Journal of Agricultural Research*, *81*(1), 46–52. https://doi.org/10.4067/S0718-58392021000100046

Boyd, N. S. (2015). Evaluation of preemergence herbicides for purple nutsedge (*Cyperus rotundus*) control in tomato. *Weed Technology*, *29*(3), 480–487. https://doi.org/10.1614/WT-D-14-00133.1

Boyd, N. S., & Reed, T. (2016). Strawberry tolerance to bed-top and drip-applied preemergence herbicides. *Weed Technology*, *30*(2), 492–498. https://doi.org/10.1614/WT-D-15-00149.1

Braverman, M. P., Lavy, T. L., & Barnes, C. J. (1986). The degradation and bioactivity of metolachlor in the soil. *Weed Science*, *34*(3), 479–484. https://doi.org/10.1017/S0043174500067242

Buckelew, J. K., Monks, D. W., Jennings, K. M., Hoyt, G. D., & Walls, R. F. (2006). Eastern black nightshade (*Solanum ptycanthum*) reproduction and interference in transplanted plasticulture tomato. *Weed Science*, *54*(3), 490–495. https://doi.org/10.1614/WS-05-060R.1

Caliskan, S., Ozkaya, I., Caliskan, M. E., & Arslan, M. (2008). The effects of nitrogen and iron fertilization on growth, yield and fertilizer use efficiency of soybean in a Mediterranean-type soil. *Field Crops Research*, *108*(2), 126–132. https://doi.org/10.1016/j.fcr.2008.04.005

Caracciolo, A. B., Giuliano, G., Grenni, P., Guzzella, L., Pozzoni, F., Bottoni, P., Fava, L., Crobe, A., Orrù, M., & Funari, E. (2005). Degradation and leaching of the herbicides metolachlor and diuron: A case study in an area of Northern Italy. *Environmental Pollution*, *134*(3), 525–534. https://doi.org/10.1016/j.envpol.2004.08.014

Carson, L. C., Ozores-Hampton, M., Morgan, K. T., & Sargent, S. A. (2014). Effects of controlled-release fertilizer nitrogen rate, placement, source, and release duration on tomato grown with seepage irrigation in Florida. *HortScience*, *49*(6), 798–806. https://doi.org/10.21273/HORTSCI.49.6.798

Chaudhari, S., Jennings, K. M., Monks, D. W., Jordan, D. L., Gunter, C. C., Basinger, N. T., & Louws, F. J. (2016). Response of eggplant (*Solanum melongena*) grafted onto tomato (*Solanum lycopersicum*) rootstock to herbicides. *Weed Technology*, *30*(1), 207–216. https://doi.org/10.1614/WT-D-15-00079.1

Collins, E. J., Bowyer, C., Tsouza, A., & Chopra, M. (2022). Tomatoes: An extensive review of the associated health impacts of tomatoes and factors that can affect their cultivation. *Biology*, *11*(2), 239. https://doi.org/10.3390/biology11020239

Curran, W. S. (2016). Persistence of herbicides in soil. *Crops & Soils*, *49*(5), 16–21. https://doi.org/10.2134/cs2016-49-0504

Curran, W. S., McGlamery, M. D., Liebi, R. A., & Lingenfelter, D. D. (1999). *Adjuvants for enhancing herbicide performance*. Penn State.

Devkota, P., Norsworthy, J. K., & Rainey, R. (2013). Efficacy and economics of herbicide programs compared to methyl bromide for weed control in polyethylene-mulched tomato. *Weed Technology*, *27*(3), 580–589. https://doi.org/10.1614/WT-D-12-00169.1

Díaz-Pérez, J. C., Phatak, S. C., Giddings, D., Bertrand, D., & Mills, H. A. (2005). Root zone temperature, plant growth, and fruit yield of tomatillo as affected by plastic film mulch. *HortScience*, *40*(5), 1312–1319. https://doi.org/10.21273/HORTSCI.40.5.1312

Di Gioia, F., Ozores-Hampton, M., Hong, J., Kokalis-Burelle, N., Albano, J., Zhao, X., Black, Z., Gao, Z., Wilson, C., Thomas, J., Moore, K., Swisher, M., Guo, H., & Rosskopf, E. N. (2016). The effects of anaerobic soil disinfestation on weed and nematode control, fruit yield, and quality of Florida fresh-market tomato. *HortScience*, *51*(6), 703–711. https://doi.org/10.21273/HORTSCI.51.6.703

Doydora, S., Hesterberg, D., & Klysubun, W. (2017). Phosphate solubilization from poorly crystalline iron and aluminum hydroxides by

AVAIL copolymer. *Soil Science Society of America Journal*, *81*(1), 20–28. https://doi.org/10.2136/sssaj2016.08.0247

El-Desouky, H. S., Islam, K. R., Bergefurd, B., Gao, G., Harker, T., Abd-El-Dayem, H., Ismail, F., Mady, M., & Zewail, R. M. Y. (2021). Nano iron fertilization significantly increases tomato yield by increasing plants' vegetable growth and photosynthetic efficiency. *Journal of Plant Nutrition*, *44*(11), 1649–1663. https://doi.org/10.1080/01904167.2021.1871749

Fageria, N. K., Baligar, V. C., & Wright, R. J. (1990). Iron nutrition of plants: An overview on the chemistry and physiology of its deficiency and toxicity. *Pesquisa Agropecuária Brasileira*, *25*(4), 553–570. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/67285/1/fageria1-pab.pdf

Fernandez, J. V., Odero, D. C., Macdonald, G. E., Ferrell, J. A., Sellers, B. A., & Wilson, P. C. (2020). Field dissipation of *S*-metolachlor in organic and mineral soils used for sugarcane production in Florida. *Weed Technology*, *34*(3), 362–370. https://doi.org/10.1017/wet.2019.121

Filimon, M. N., Roman, D. L., Caraba, I. V., & Isvoran, A. (2021). Assessment of the effect of application of the herbicide *S*-metolachlor on the activity of some enzymes found in soil. *Agriculture*, *11*(6), 469. https://doi.org/10.3390/agriculture11060469

Fontanelli, M., Martelloni, L., Raffaelli, M., Frasconi, C., Ginanni, M., & Peruzzi, A. (2015). Weed management in autumn fresh market spinach: A nonchemical alternative. *HortTechnology*, *25*(2), 177–184. https://doi.org/10.21273/HORTTECH.25.2.177

Franzen, D. W., O'Barr, J. H., & Zollinger, R. K. (2003). Interaction of a foliar application of iron HEDTA and three postemergence broadleaf herbicides with soybeans stressed from chlorosis. *Journal of Plant Nutrition*, *26*(12), 2365–2374. https://doi.org/10.1081/PLN-120025465

Freeman, J. H., Frey, C., Kanissery, R., Smith, H. A., Desaeger, J., & Vallad, G. E. (2022). Tomato production. In *Vegetable production handbook of Florida* (pp. 1–86). University of Florida. https://doi.org/10.32473/edis-cv137-2022

Freeman, J. H., McAvoy, E. J., Boyd, N. S., Dittmar, P. J., Ozores-Hampton, M., Smith, H. A., Vallad, G. E., & Webb, S. E. (2016). *Tomato production* (EDIS HS739). University of Florida IFAS Extension. https://edis.ifas.ufl.edu/pdffiles/cv/cv13700.pdf

Gairhe, B., Liu, W., Batuman, O., Dittmar, P., Kadyampakeni, D., & Kanissery, R. (2021). Environmental fate and behavior of the herbicide glyphosate in sandy soils of Florida under citrus production. *Frontiers in Environmental Chemistry*, *2*, 737391. https://doi.org/10.3389/fenvc.2021.737391

Galon, L., De David, F. A., Forte, C. T., Júnior, F. W. R., Radunz, A. L., Kujawinski, R., Radunz, L. L., Castoldi, C. T., Perin, G. F., & Mossi, A. J. (2018). Chemical management of weeds in corn hybrids. *Weed Biology and Management*, *18*(1), 26–40. https://doi.org/10.1111/wbm.12141

Garvey, P. V., Meyers, S. L., Monks, D. W., & Coble, H. D. (2013). Influence of Palmer amaranth (*Amaranthus palmeri*) on the critical period for weed control in plasticulture-grown tomato. *Weed Technology*, *27*(1), 165–170. https://doi.org/10.1614/WT-D-12-00028.1

Geier, P. W., & Stahlman, P. W. (2009). Nitrogen concentration and application timing affect imazamox efficacy in winter wheat. *Crop Protection*, *28*(7), 573–576. https://doi.org/10.1016/j.cropro.2009.03.003

Götz, T., & Böger, P. (2004). The very-long-chain fatty acid synthase is inhibited by chloroacetamides. *Zeitschrift für Naturforschung C*, *59*(7–8), 549–553. https://doi.org/10.1515/znc-2004-7-818

Grichar, W. J., Nester, P. R., & Colburn, A. E. (1992). Nutsedge (*Cyperus* spp.) control in peanuts (*Arachis hypogaea*) with imazethapyr. *Weed Technology*, *6*(2), 396–400. https://doi.org/10.1017/S0890037X0003493X

Güler, S., & Büyük, G. (2007). Relationships among chlorophyll-meter reading value, leaf N and yield of cucumber and tomatoes. *Acta Horticulturae*, *729*, 307–311. https://doi.org/10.17660/ActaHortic.2007.729.50

Hasanuzzaman, M., Mohsin, S. M., Bhuyan, M. B., Bhuiyan, T. F., Anee, T. I., Masud, A. A. C., & Nahar, K. (2020). Phytotoxicity, environmental and health hazards of herbicides: Challenges and ways forward. In M. N. V. Prasad (Ed.). *Agrochemicals detection, treatment and remediation* (pp. 55–99). Butterworth-Heinemann (Elsevier) Oxford. https://doi.org/10.1016/B978-0-08-103017-2.00003-9

He, W., Shohag, M. J. I., Wei, Y., Feng, Y., & Yang, X. (2013). Iron concentration, bioavailability, and nutritional quality of polished rice affected by different forms of foliar iron fertilizer. *Food Chemistry*, *141*(4), 4122–4126. https://doi.org/10.1016/j.foodchem.2013.07.005

Heap, I. (2014). Global perspective of herbicide-resistant weeds. *Pest Management Science*, *70*(9), 1306–1315. https://doi.org/10.1002/ps.3696

Hochmuth, G., & Hanlon, E. (2011). A Summary of N, P, and K Research with Tomato in Florida: SL355/CV236, rev. 8/2011. *EDIS*, *2011*(10). https://edis.ifas.ufl.edu/publication/CV236

Holm, L. G., Plucknett, D. L., Pancho, J. V., & Herberger, J. P. (1977). *The world's worst weeds. Distribution and biology*. University Press of Hawaii.

Hopkins, B. G., Fernelius, K. J., Hansen, N. C., & Eggett, D. L. (2018). AVAIL phosphorus fertilizer enhancer: Meta-analysis of 503 field evaluations. *Agronomy Journal*, *110*(1), 389–398. https://doi.org/10.2134/agronj2017.07.0385

Jiang, C., Johkan, M., Hohjo, M., Tsukagoshi, S., & Maruo, T. (2017). A correlation analysis on chlorophyll content and SPAD value in tomato leaves. *HortResearch*, *71*, 37–42. https://doi.org/10.20776/S18808824-71-P37

Kanissery, R., Liu, W., Tiwari, R., & Sims, G. (2021). Impact of soil aeration on the environmental fate of pre-emergent herbicide metolachlor. *Applied Sciences*, *11*(18), 8567. https://doi.org/10.3390/app11188567

Klein, R. (2008). *Combining weed and feed treatments for winter wheat*. Institute of Agricultural and Natural Resources, CROPWATCH, University of Nebraska–Lincoln. https://cropwatch.unl.edu/combining-weed-and-feed-treatments-winter-wheat

Kouame, K. B.-J., Savin, M. C., Willett, C. D., Bertucci, M. B., Butts, T. R., Grantz, E., & Roma-Burgos, N. (2022). *S*-metolachlor persistence in soil as influenced by within-season and inter-annual herbicide use. *Environmental Advances*, *9*, 100318. https://doi.org/10.1016/j.envadv.2022.100318

Kumari, V. V., Banerjee, P., Verma, V. C., Sukumaran, S., Chandran, M. A. S., Gopinath, K. A., Venkatesh, G., Yadav, S. K., Singh, V. K., & Awasthi, N. K. (2022). Plant nutrition: An effective way to alleviate abiotic stress in agricultural crops. *International Journal of Molecular Sciences*, *23*(15), 8519. https://doi.org/10.3390/ijms23158519

Lindsay, W. L. (1984). Soil and plant relationships associated with iron deficiency with emphasis on nutrient interactions. *Jour-*

nal of Plant Nutrition, *7*(1–5), 489–500. https://doi.org/10.1080/01904168409363215

Lindsay, W. L., & Schwab, A. P. (1982). The chemistry of iron in soils and its availability to plants. *Journal of Plant Nutrition*, *5*(4–7), 821–840. https://doi.org/10.1080/01904168209363012

Lobartini, J. C., & Orioli, G. A. (1988). Absorption of iron Fe-humate in nutrient solutions by plants. *Plant and Soil*, *106*, 153–157. https://doi.org/10.1007/BF02371209

Lucena, J. L., Gárate, A., & Carpena, O. (1987). Iron-chelates evaluation in a calcareous soil. *Plant and Soil*, *103*, 134–138. https://doi.org/10.1007/BF02370679

Miller, M. R., & Dittmar, P. J. (2014). Effect of PRE and POST-directed herbicides for season-long nutsedge (*Cyperus* spp.) control in bell pepper. *Weed Technology*, *28*(3), 518–526. https://doi.org/10.1614/WT-D-13-00181.1

Monje, O. A., & Bugbee, B. (1992). Inherent limitations of nondestructive chlorophyll meters: A comparison of two types of meters. *HortScience*, *27*(1), 69–71. https://doi.org/10.21273/HORTSCI.27.1.69

Morales-Payan, J. P., Santos, B. M., Stall, W. M., & Bewick, T. A. (1997). Effects of purple nutsedge (*Cyperus rotundus*) on tomato (*Lycopersicon esculentum*) and bell pepper (*Capsicum annuum*) vegetative growth and fruit yield. *Weed Technology*, *11*(4), 672–676. https://doi.org/10.1017/S0890037X00043232

Morales-Payan, J. P., Stall, W. M., Shilling, D. G., Charudattan, R., Dusky, J. A., & Bewick, T. A. (2003). Above-and belowground interference of purple and yellow nutsedge (*Cyperus* spp.) with tomato. *Weed Science*, *51*(2), 181–185. https://doi.org/10.1614/0043-1745(2003)051[0181:AABIOP]2.0.CO;2

Motis, T. N., Locascio, S. J., & Gilreath, J. P. (2001). Yellow nutsedge interference effects on fruit weight of polyethylene-mulched bell pepper. *Proceedings of the Florida State Horticultural Society*, *114*, 268–271.

Murphy, L., & Sanders, L. (2007). Improving N and P use efficiency with polymer technology. In T. Vyn (Ed.), *2007 Indiana CCA conference proceedings (CD-AY-330)* (pp. 1–13). Purdue University. http://www.agry.purdue.edu/CCA/2007/

National Agricultural Statistics Service. (2022). *Southern Region news release vegetables*. National Agricultural Statistics Service.

Obrigawitch, T., Hons, F. M., Abernathy, J. R., & Gipson, J. R. (1981). Adsorption, desorption, and mobility of metolachlor insoils. *Weed Science*, *29*(3), 332–336. https://doi.org/10.1017/S0043174500062068

Pannacci, E., Lattanzi, B., & Tei, F. (2017). Non-chemical weed management strategies in minor crops: A review. *Crop Protection*, *96*, 44–58. https://doi.org/10.1016/j.cropro.2017.01.012

Peng, S., García, F. V., Laza, R. C., & Cassman, K. G. (1993). Adjustment for specific leaf weight improves chlorophyll meter's estimate of rice leaf nitrogen concentration. *Agronomy Journal*, *85*(5), 987–990. https://doi.org/10.2134/agronj1993.00021962008500050005x

Rachuy, J. S., & Fennimore, S. A. (2022). Evaluation of sulfentrazone and *S*-metolachlor in brassica vegetables. *Weed Technology*, *36*(4), 592–596. https://doi.org/10.1017/wet.2022.39

Rhue, R. D., & Everett, P. H. (1987). Response of tomatoes to lime and phosphorus on a sandy soil. *Agronomy Journal*, *79*(1), 71–77. https://doi.org/10.2134/agronj1987.00021962007900010015x

Salama, K., & Geyer, M. (2023). Plastic mulch films in agriculture: Their use, environmental problems, recycling and alternatives. *Environments*, *10*(10), 179. https://doi.org/10.3390/environments10100179

Sandhu, R. K., Boyd, N. S., Zotarelli, L., Agehara, S., & Peres, N. (2021). Effect of planting density on the yield and growth of intercropped tomatoes and peppers in Florida. *HortScience*, *56*(2), 286–290. https://doi.org/10.21273/HORTSCI15567-20

Sandhu, R. K., Reuss, L. E., & Boyd, N. S. (2022). Evaluation of sulfentrazone alone or in combination with other PRE and POST herbicides for weed control in tomato (*Solanum lycopersicum*) and strawberry (*Fragaria* × *ananassa*). *HortScience*, *57*(2), 215–220. https://doi.org/10.21273/HORTSCI16265-21

Santos, B. M., Gilreath, J. P., Motis, T. N., Noling, J. W., Jones, J. P., & Norton, J. A. (2006). Comparing methyl bromide alternatives for soilborne disease, nematode and weed management in fresh market tomato. *Crop Protection*, *25*(7), 690–695. https://doi.org/10.1016/j.cropro.2005.09.015

Senseman, S. A. (2007). *Herbicide handbook* (No. 632.954 W394h9). Weed Science Society of America.

Shan, Y., Cao, L., Muhammad, B., Xu, B., Zhao, P., Cao, C., & Huang, Q. (2020). Iron-based porous metal–organic frameworks with crop nutritional function as carriers for controlled fungicide release. *Journal of Colloid & Interface Science*, *566*, 383–393. https://doi.org/10.1016/j.jcis.2020.01.112

Shaner, D. L. (2014). *Herbicide handbook* (No. 632.954 W394h10). Weed Science Society of America.

Simonne, E., Sudstill, D., Hochmuth, B., Olczyk, T., Dukes, M., Munoz-Carpena, R., & Li, Y. (2003). *Drip irrigation: The BMP era—An integrated approach to water and fertilizer management for vegetables grown with plasticulture* (Publication #HS917). University of Florida, The Institute of Food and Agriculture Science Extension. https://edis.ifas.ufl.edu/publication/HS172

Summerhays, J. S., Jolley, V. D., Hill, M. W., & Hopkins, B. G. (2017). Enhanced phosphorus fertilizers (Carbond P® and AVAIL®) supplied to maize in hydroponics. *Journal of Plant Nutrition*, *40*(20), 2889–2897. https://doi.org/10.1080/01904167.2017.1384007

Timilsina, N., Batuman, O., Alferez, F., Kadyampakeni, D., Tiwari, R., & Kanissery, R. (2023). Nontarget effects of preemergence herbicide diuron in Hamlin and Valencia sweet orange (*Citrus sinensis* L. Osbek) in Florida. *HortScience*, *58*(12), 1492–1497. https://doi.org/10.21273/HORTSCI17359-23

Tiwari, R., Bashyal, M., & Kanissery, R. (2022). Weed management strategies for tomato plasticulture production in Florida. *Plants*, *11*(23), 3292. https://doi.org/10.3390/plants11233292

Tiwari, R., Reinhardt Piskáčková, T. A., Devkota, P., Mulvaney, M. J., Ferrell, J. A., & Leon, R. G. (2021). Growing winter *Brassica carinata* as part of a diversified crop rotation for integrated weed management. *Global Change Biology Bioenergy*, *13*(3), 425–435. https://doi.org/10.1111/gcbb.12799

USDA NASS. (2020). *Vegetables 2019 summary*. U.S. Department of Agriculture, National Agricultural Statistics Service.

Weber, J. B., Mckinnon, E. J., & Swain, L. R. (2003). Sorption and mobility of 14C-labeled imazaquin and metolachlor in four soils as influenced by soil properties. *Journal of Agricultural and Food Chemistry*, *51*(19), 5752–5759. https://doi.org/10.1021/jf021210t

Webster, T. M. (2005). Patch expansion of purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*) with and without polyethylene mulch. *Weed Science*, *53*(6), 839–845. https://doi.org/10.1614/WS-05-045R.1

Wilson, G. C. S. (1985). Tomato production in different growing media. In *Symposium on nutrition, growing techniques and plant substrates*

(Vol. 178, pp. 115–120). International Society for Horticultural Science.

Yu, J., Sharpe, S. S., & Boyd, N. S. (2020). PRE herbicides and POST halosulfuron for purple nutsedge control in tomato grown in plasticulture systems. *Weed Technology*, *34*(5), 642–646. https://doi.org/10.1017/wet.2020.24

Yu, J., Vallad, G. E., & Boyd, N. S. (2019). Evaluation of allyl isothiocyanate as a soil fumigant for tomato (*Lycopersicon esculentum* Mill.) production. *Plant Disease*, *103*(11), 2764–2770. https://doi.org/10.1094/PDIS-11-18-2013-RE

Zargar, M., Bayat, M., Lyashko, M., & Chauhan, B. (2019). Postemergence herbicide applications impact Canada thistle control and spring wheat yields. *Agronomy Journal*, *111*(6), 2874–2880. https://doi.org/10.2134/agronj2019.02.0125

Zhang, M., Her, Y. G., Migiliaccio, K. W., & Fraisse, C. W. (2017). Florida rainfall data sources and types: AE517, 1/2017. *EDIS*, *2017*(2), 5–5. https://edis.ifas.ufl.edu/publication/AE517

Zimdahl, R. L. (2004). *Weed–crop competition: A review* (2nd ed.). Wiley-Blackwell.

How to cite this article: Tiwari, R., Sapkota, A., Boyd, N., & Kanissery, R. (2024). Purple nutsedge management in tomato plasticulture: A study on the effectiveness of preemergence herbicide *S*-metolachlor and its co-application with fertilizer enhancer and chelated iron. *Agrosystems, Geosciences & Environment*, *7*, e20563. https://doi.org/10.1002/agg2.20563