Adaptation of Palmer amaranth (*Amaranthus palmeri*) to agroecossystems

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ABSTRACT

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Keywords: Text Text Text Text Text Text Evolution Weed

INTRODUCTION

Palmer amaranth (*Amaranthus palmeri* S. Watson) is currently considered one of the most economically damaged weed species to cropping systems in the United States (Ward et al., 2013). The species has showed a remarkable capacity to evolve resistance to herbicides. Palmer amaranth has evolved resistance to eight herbicide sites of action (Heap, 2021), increasing the weed management complexity (Lindsay et al., 2017). Uncontrolled Palmer amaranth in competition for water, light and nutrients can drastically reduce crop yields (Berger et al., 2015). Palmer amaranth is documented with potential to reduce 91%, 68%, and 54% of corn (Massinga et al., 2001), soybean (Klingaman and Oliver, 1994), and cotton (Morgan et al., 2001) yields, respectively.

Palmer amaranth is a fast growing summer annual forb indigenous to Sonoran Desert (Sauer, 1957). The species would eventually emerge as a threat to US agriculture in the 1990s. Palmer amaranth weediness is likely a result of human-assisted selection in combination with species biology. Farm mechanization, conservation agriculture (e.g., no-till), and reliance on herbicides for weed management are the main human mediated selection of Palmer amaranth to cropping systems. On the other hand, Palmer amaranth is a prolific seed producer with a C4 photosynthetic apparatus (Ward et al., 2013). With a dioecy nature, Palmer amaranth male and female plants are obligate outcrosser species, increasing the chances of exchanging herbicide resistant alleles among plants (Oliveira et al., 2018). Also, Palmer amaranth small seed size (e.g, 1 mm) tend to thrive in no-tillage systems (Price et al., 2011), and spread across locations through farm equipment (Sauer, 1972), manure (Hartzler and Anderson, 2016), animals (Farmer et al., 2017), and plant propagules (Yu et al., 2021). Therefore, Palmer amaranth dispersal capacity make the species one of the most successful cases of weed adaption to cropping systems.

Light and temperature are likely the main environment requirements for Palmer amaranth successful adaptation. Palmer amaranth is reported with an extended germination period (Jha et al., 2010). Germination of Palmer amaranth is triggered by 18 C soil temperature (Keeley et al., 1987), and optimal germination and biomass production occur at 35/30 C day and night temperatures (Guo and Al-Khatib, 2003). Water has not shown to limit Palmer amaranth fitness. Under continuous water stress, Palmer amaranth survived and produced at least 14000 seeds plant-1 (Chahal et al., 2018). Also, seeds from Palmer amaranth growing under water stress conditions were heavier, less dormant, and prompt for germination (Matzrafi et al., 2021). The continuous global temperature warming can impact agriculture and promote niches for Palmer amaranth invasion/adaptation into new environments. Currently, it is estimated that the greatest climatic risk of Palmer amaranth establishment is agronomic crops in Australia and Sub-Sahara Africa (Kistner and Hatfield, 2018). Temperature is a key factor limiting Palmer amaranth expansion to cooler geographies (Briscoe Runquist et al., 2019); however, under future climate change Palmer amaranth is likely to expand northward into Canada and Northern Europe (Kistner and Hatfield, 2018; Briscoe Runquist et al., 2019).

Palmer amaranth is already documented in agronomic crops of South America (Larran et al., 2017; Küpper et al., 2017) and Southern Europe (Milani et al., 2021). In the US, Palmer amaranth is established at crop (Garetson et al., 2019) and non-crop land (Bagavathiannan and Norsworthy, 2016) in the warm southern United States but its range is expanding to cool temperatures northward. For example, herbicide resistant Palmer amaranth is widespread in Nebraska (Oliveira et al., 2021), Michigan (Kohrt et al., 2017), and Connecticut (Aulakh et al., 2021). Successful cases of Palmer amaranth invasion and near to eradication is reported in Minnesota (Yu et al., 2021). No Palmer amaranth actively growing was found in Canada; however, Palmer amaranth seeds was detected in sweet potato slips (Page et al., 2021). Nonetheless, it seems fated to manage Palmer amaranth in agronomic crops throughout multiple environments in the near future. Therefore, strategies on Palmer amaranth management should encompass the agroecosystem level but not attempts to eradicate the weed. Most tactics to manage Palmer amaranth are based technology fixes (Scott, 2011), which are short-term (e.g., herbicide and/or tillage) rather than long-term ecological management.

The continuous Palmer amaranth dispersal and potential establishment into northern United States warrant investigations on species morphology growing in such environments. Understanding Palmer amaranth biology and growing strategies under different agroecossystems can enhance our knowledge on species adaptation. It can also aid on designing proactive and ecological tactics to limit the species range expansion, reduce its negative impact, and design resilient and sustainable farming systems (MacLaren et al., 2020). Therefore, the objective of this study was to investigate the flowering pattern, biomass production, and height of Palmer amaranth growing under in corn, soybean and fallow at two timings across five locations in the mid/upper United States Midwest.

MATERIAL AND METHODS

Plant material and growing conditions

The study was performed with a *A. palmeri* accession (Per1) from Perkins County, Nebraska. Per1 accession collection is documented with no reported herbicide resistance (Oliveira et al., 2021). Three weeks prior to the field experiment, seeds were planted in plastic trays containing potting-mix. Emerged seedlings (1 cm) were transplanted into 200 cm-3 plastic pots (a plant pot-1). Palmer amaranth seedlings were supplied with adequate water and kept under greenhouse conditions at Arlington, Clay Center, Lincoln, and Macomb; and kept outdoors in Grant. Palmer amaranth seedlings were kept under greenhouse/outdoors until the onset of the experiment (7 to 10 cm height).

Field study

The experiment was conducted in 2018 and 2019 under field conditions at five locations: Arlington (Washington County, Wisconsin), Clay Center (Clay County, Nebraska), Grant (Perkins County, Nebraska), Lincoln (Lancaster County, Nebraska), and Macomb (McDonough County, Illinois).

The field experimental unit were six adjacent 9.1 m wide (12 rows at 72.2 cm row spacing) by 10.7 m long. Each experimental unit was planted with corn or soybean, or under fallow condition. Palmer amaranth seedlings were transplanted to the field experiment by making a whole in the soil (6 cm deep and 8 cm wide); and gently transferring to the ground (potting mix + two seedlings). After a week, one was eliminated and one was kept. There were two transplant timing: first (June 1^{st}) and second (July 1^{st}). There were 24 Palmer amaranth plants in each experimental unit, with a total of 144 plants. The study was repeated twice.

After transplanting, Palmer amaranth flowering was monitored until the end of the study. When a plant started flowering, the day was recorded, plant sex was identified as male or female, and plant height was measured from soil surface to the plant top. Then, aboveground plant biomass was harvest near soil surface and oven dried at 65 C until reaching constant weight before the weight of biomass (g $plant^{-1}$) was recorded.

Statistical analyses

The statistical analyses were performed using R statistical software version 4.0.1. Data across locations and year were combined.

The cumulative Palmer amaranth flowering estimation was determined using a asymmetrical three parameter log logistic Weibull model of the drc package (Ritz et al., 2015).

$$Y(x) = 0 + (d - 0)exp(-exp(b(log(x) - e)))$$

In this model, *Y* is the Palmer amaranth cumulative flowering, *d* is the upper limit (set to 100), and *e* is the XXX, and *x* day of year (doy).

The doy for 10, 50, and 90% Palmer amaranth cumulative flowering were determined using the *ED* function of drc package. Also, the 10, 50, and 90% Palmer amaranth cumulative flowering were compared among crop/fallow and timings using the *EDcomp* function of drc package. The EDcomp function compares the ratio of cumulative flowering using t-statistics, where P-value < 0.05 indicates that we fail to reject the null hypothesis.

Palmer amaranth height and biomass were performed with a linear mixed model using *lmer* function from “lme4” package (Bates et al., 2015). Plant height and biomass were transformed to meet model assumption of normality . In the model, agroecosystem (crop, soybean, fallow) was the fixed effect and year nested with location the random effects. Analysis of variance was performed with *anova* function from “car” package (Fox and Weisberg, 2018). Marginal means and compact letter display were estimated with *emmeans* and *cld* from packages “emmeans” and multcomp (Hothorn et al., 2008)

RESULTS

Subsection 1

You can use `R` chunks directly to plot graphs.

Subsection 2

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1 DISCUSSION

DISCLOSURE/CONFLICT-OF-INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

MCO design, wrote,

The statement about the authors and contributors can be up to several sentences long, describing the tasks of individual authors referred to by their initials and should be included at the end of the manuscript before the References section.

ACKNOWLEDGMENTS

Funding:

2 SUPPLEMENTAL DATA

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3 REFERENCES

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FIGURES

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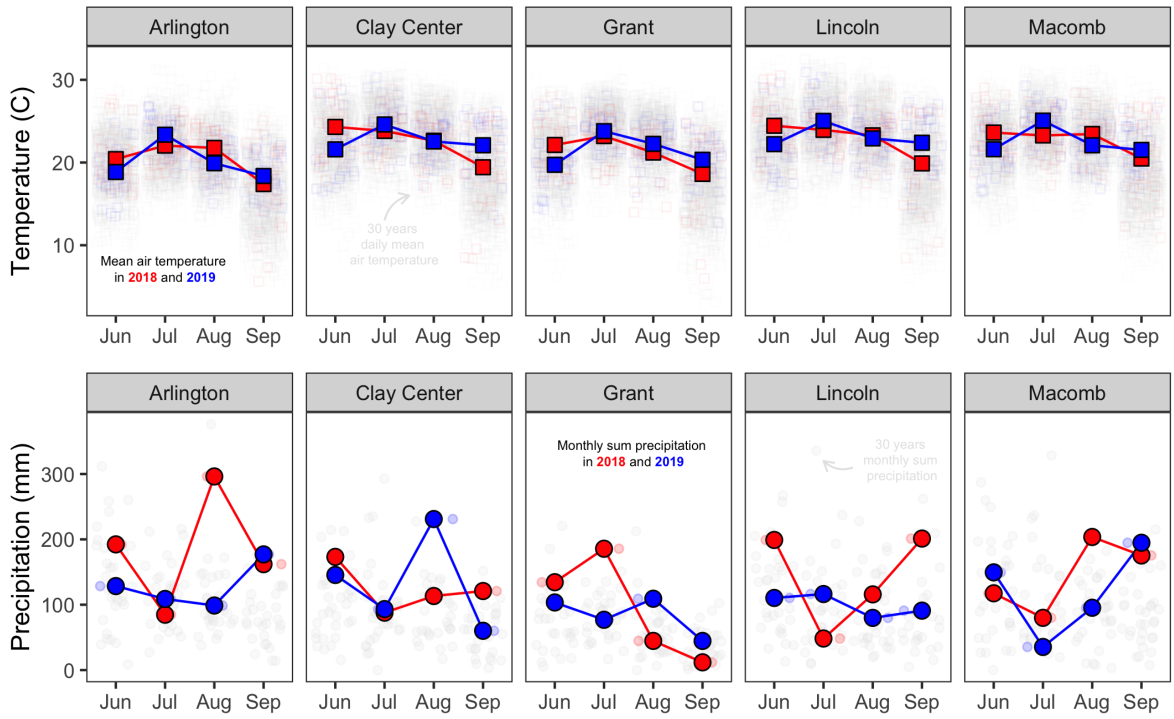

Figure 1. Mean average temperature (C) and montly sum precipitation (mm) at Arlington, WI, Clay Center, NE, Grant, NE, Lincoln, NE and Macomb, IL

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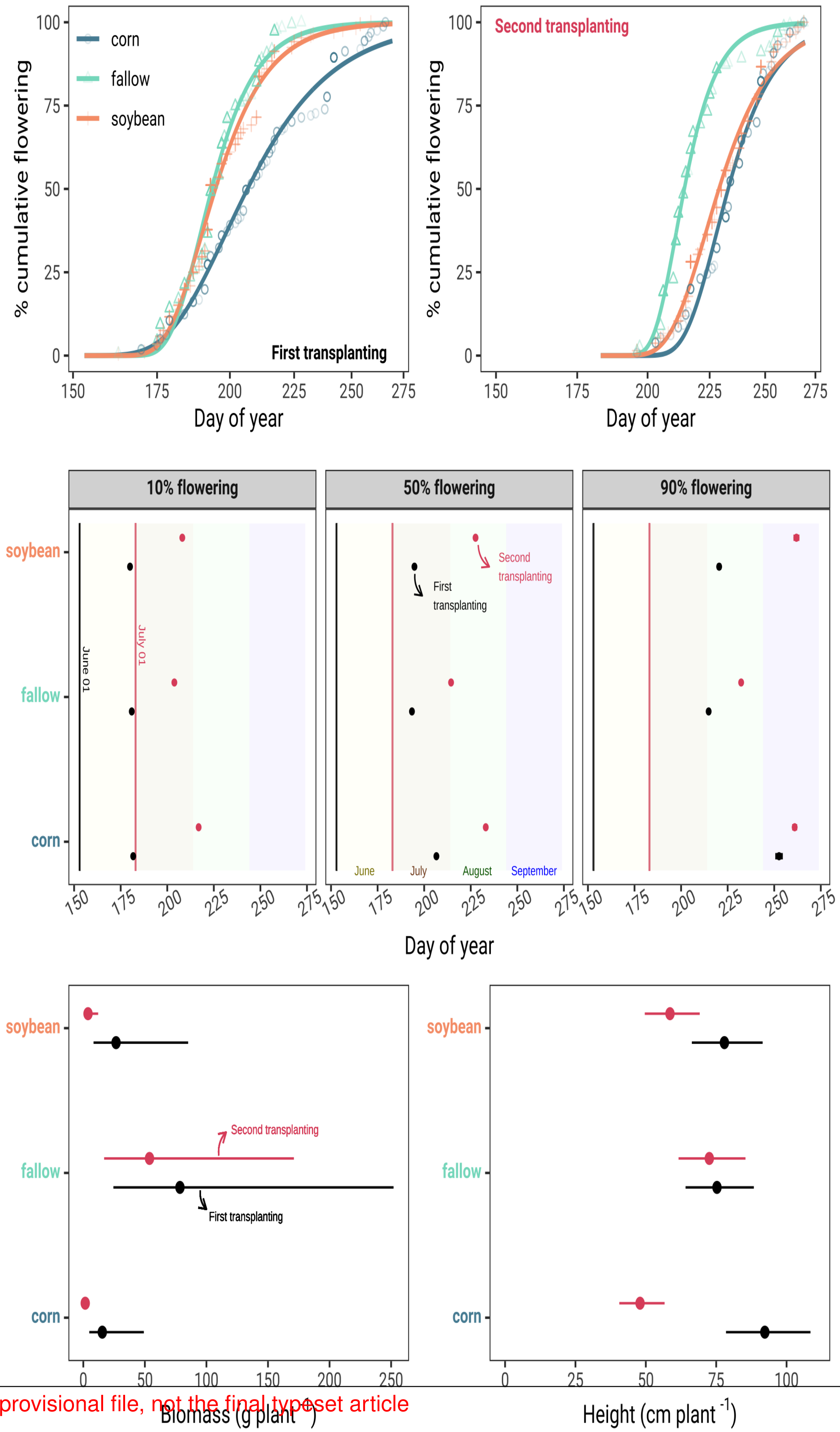

Figure 2. Figure caption

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