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Weed Seedbank Management: Revisiting How Herbicides Are Evaluated

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My View

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Abstract

There is great value in quantifying and reporting weed seed production as a component of herbicide efficacy evaluations for two reasons. First, visual weed control ratings and associated measurements such as weed density and biomass are not sufficient indicators of fecundity. Second, knowledge of fecundity associated with herbicide treatments can guide the development of effective management programs that impact long-term weed population dynamics and reduce the risk of herbicide resistance.

Background

As a discipline, our science and the ways in which research is conducted must continue to evolve. In this paper, we discuss how current weed control assessments are not robust and suggest improvements to existing approaches. Even before the first published papers in the journal *Weeds* (known today as *Weed Science*), the effectiveness of a herbicide was based on a visual control assessment, among other criteria, relative to a nontreated control (Binns et al. 2000). While this does allow for rapid evaluation of herbicide efficacy qualitatively, it does little to inform potential weed seed rain associated with a given herbicide treatment. Here, we argue that a strong consideration of weed fecundity assessment is vital in evaluating herbicide treatments. In the very first issue of *Weeds*, Stamper and Chilton (1951), in their report entitled "Johnson Grass Control in Sugarcane," pointed to the fact that understanding weed seed production, in addition to efficacy of treatments, is important for formulating viable solutions.

Today, the vast majority of studies focused on the assessment of herbicide performance rely heavily on qualitative efficacy ratings, with crop yield being the only quantitative biological information collected from such evaluations; fecundity of weeds is rarely determined for herbicide treatments. Researchers have traditionally placed little emphasis on measuring seed rain from herbicide evaluation experiments due primarily to the adoption of economic threshold-based weed management approaches. However, given the current scenario of burgeoning herbicide-resistance cases, a core principle of resistance management is the prevention of weed seed production, at least for those weeds that pose high risk for resistance evolution (Bagavathiannan and Norsworthy 2012; Norsworthy et al. 2012), supporting a zero-threshold-based weed management strategy (Barber et al. 2015).

The authors believe that there is great value in quantifying and reporting weed seed production as a component of herbicide efficacy evaluations for two reasons: (1) visual weed control ratings and associated measurements such as weed density and biomass are not sufficient indicators of fecundity, and (2) knowledge of fecundity associated with herbicide treatments can guide the development of effective management programs that impact long-term weed population dynamics and reduce the risk of herbicide resistance.

Meta-analysis Reveals a Lack of Association between Visual Ratings and Fecundity

To better understand what data are routinely collected in trials involving herbicide efficacy evaluations, we conducted a meta-analysis based on a literature survey in the journals *Weed Science* and *Weed Technology* from 1970 and 2010 onward, respectively, using "herbicide efficacy," "herbicide evaluation," or "herbicide assessment" as key words. In total, 3,496 articles were revealed to use these key words. They were further screened using the key words "seed production," "soil seedbank," "fecundity," or "belowground reproductive organs [i.e., tubers]" (coded as "seed production" in metadata analysis) to determine the extent of such measurements in published literature. Only 81 of these 3,496 articles, 60 and 21 from *Weed Science* and *Weed Technology*, respectively, contained these key words. Additional information extracted from these 81 articles fell into the categories of "visual rating," "visual observations," "rating,"

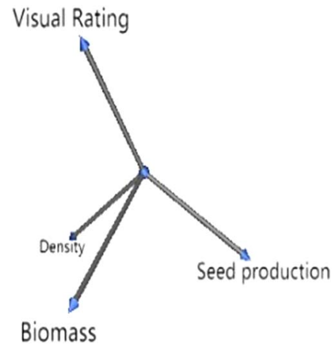

Figure 1. Scatter plot of principal component analysis indicating the (dis) associations between visual rating, weed seed production, weed biomass and density as a result of meta-analysis of selected research articles in *Weed Science* and *Weed Technology*.

or "percentage control" (coded as "visual rating"); "population dynamics," "weed counts," "population structure," or "weed density" (coded as "density"); "biomass," "dry matter," or "aboveground biomass" (coded as "biomass"); herbicide active ingredient (coded as "herbicide"); and site-of-action group (based on WSSA classification code). Further information pertaining to the journal, publication year, duration of research, weed species, crop, and crop yield was also noted.

A lack of association between visual weed control rating, weed biomass, weed seed production, and to some extent, weed density was revealed when a principal component analysis (PCA) was performed on these characteristics (Figure 1).

The PCA explained 65% of the metadata variability. Weed density was the only variable that was found to be at least marginally associated with visual ratings. Quantitative measurements of the "weed stand" usually accompany visual observations, as a means to reduce the subjectivity associated with visual assessments (European and Mediterranean Plant Protection Organization [EPPO] 2012). However, the degree of collinearity between these two parameters needs to be considered. This collinearity depends on how numeric ratings are distributed around a designated threshold or cutoff point (Goldberger 2008), which can affect the minimum detectable effect size, that is, the smallest treatment effect that a research design has an acceptable chance of detecting whether it exists (Jacob et al. 2012). In the present metadata analysis, only 43 research trials (research articles) dominated by soybean [*Glycine max* (L.) Merr.], corn (*Zea mays* L.), and small grain cereals (i.e., wheat [*Triticum aestivum* L.], rice [*Oryza sativa* L.], and barley [*Hordeum vulgare* L.]), continued to crop maturity as indicated by crop yield recordings; this reflects an even smaller percentage (1.2%) of the total herbicide efficacy trials that have been published in both journals. Findings of the meta-analysis clearly indicate that visual ratings and biomass estimation are not sufficient measures of weed fecundity and that quantification of weed seed production is important to fully evaluate long-term impacts of current weed management programs.

Knowledge of Weed Fecundity Informs Effective Weed Management Programs

The long-term impact of a given herbicide program on weed population dynamics (for annual weeds) is directly related to the reduction in weed seed production potential associated with the herbicide treatments. The amount of seed that enters the soil seedbank over a number of seasons will affect the sustainability of any weed control strategy (Grundy et al. 2004). Seed production, albeit minimal at times, ensures the persistence of the weed population. Therefore, knowledge of weed seed production, which is an important element of weed population dynamics, is required for the development of sustainable weed management strategies (Norris 2003)

Reducing weed fecundity following a herbicide treatment is also vital for minimizing the risk of herbicide-resistance evolution (Bagavathiannan and Norsworthy 2012).

The actual mutation rate for herbicide resistance is not known for most weeds, but the natural, spontaneous mutation rate for a single gene is estimated between 1×10^{-5} and 1×10^{-6} per generation (Mortimer et al. 1992). High levels of fecundity of several weed species mean that there is a high likelihood for the occurrence of rare resistant individuals in a population. Palmer amaranth (*Amaranthus palmeri* S. Wats.), for example, has been reported to produce more than 600,000 seeds $plant^{-1}$ (Keeley et al. 1987). It is highly possible, based on these numbers, that herbicide resistance will eventually evolve or a small frequency of resistant individuals is already present in some fields, remaining unnoticed because weed control is rarely absolute (Mallory-Smith et al. 1990).

Herbicide-resistance simulation models (e.g., Bagavathiannan et al. 2013; Neve et al. 2011) have clearly demonstrated that the risk of resistance is proportional to the soil seedbank size. Thus, a strong emphasis on minimizing weed seed production is of paramount importance, with zero seed production in systems vulnerable to herbicide-resistance evolution (Barber et al. 2015). Today, a user-friendly software (Palmer Amaranth Management Model [PAM]) is available for *A. palmeri* management to bring grower attention to soil seedbank management and an understanding of the impact various management practices have on weed fecundity (Lindsay et al. 2017). The PAM software demonstrates the value of reducing seedbank inputs for improving long-term economic returns as well as curtailing weed population growth. Thus, weed management programs must aim at reducing weed fecundity, especially in systems vulnerable to herbicide-resistance evolution. Consequently, the robustness of herbicide weed control experiments must be evaluated based on an assessment of weed seed rain in the plots, in addition to other qualitative assessments. Collection of fecundity data in herbicide efficacy trials will further aid the construction and improvement of biological models such as PAM. Moreover, weed population demographics and/or weed seed production provide information on characteristics directly related to the spread of herbicide resistance (Korres and Norsworthy 2017; Norsworthy et al. 2016) as a function of an agroecological niche, time or year of herbicide application, and climate, among others (Streibig 2003). Consequently, comprehensive evaluation of herbicide efficacy, including seed production, which is crucial to understanding weed population dynamics and predicting the evolution of herbicide resistance, aids the development of more biologically sound and effective weed management systems.

It is acknowledged that reporting herbicide efficacy alone is reasonable during herbicide discovery or when initially characterizing a new herbicide before labeling. In these types of experiments, crops may or may not be included, and if included, are seldom continued to maturity due to the crop destruction requirements for unregistered herbicides. As a result, quantification of weed seed production may not be feasible or required in these experiments. However, weed seed production potential should be considered in the evaluation of management programs involving commercially available herbicides. While quantification of seed production can be tedious for large-scale experiments, at the very least one could qualitatively estimate seed production with minimal effort.

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