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A meta-analysis of field bindweed (*Convolvulus arvensis* L.) and Canada thistle (*Cirsium arvense* L.) management in organic agricultural systems

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ABSTRACT

Organic farming has become a major agricultural and economic sector, and weed management is one of the primary challenges facing the industry. Of particular concern are rhizomatous perennial weeds such as field bindweed (*Convolvulus arvensis* L.) and Canada thistle [*Cirsium arvense* (L.) Scop.] which are highly competitive and not easily controlled in organic systems. We conducted meta-analyses of the existing literature to 1) identify promising management approaches for these weeds in the absence of synthetic herbicides and 2) determine which aspects of field bindweed and Canada thistle management warrant further study. Mechanical control (i.e. plowing, cultivation, hoeing) was the most studied management category in annual cropping systems, accounting for 40% of data extracted, but did not outperform most of the other management actions overall, possibly due to the variability in specific methodology (i.e. timing, frequency, depth, implement). In annual systems, integrated management, or the combination of two or more control methods, emerged as the management technique that caused the greatest decrease in abundance and survival for field bindweed. We identified several additional management techniques that decreased field bindweed and/or Canada thistle in both annual and perennial systems including biocontrol, mowing, grazing, crop diversification, solarization, shading, flaming, and crop competition. However, organic producers continue to struggle with these species. This discrepancy may originate from the fact that most of the studies we evaluated reported impacts over short time spans, with 53% being conducted for a period of one to two years, and only 9% conducted for five or more years. Further, only 16% of field bindweed and 26% of Canada thistle studies reported measures of variability. Longer-term research focused on sustainable perennial weed management systems is needed in addition to research about short-term interventions.

1. Introduction

With $43 billion in annual sales, consumer demand for organic products showing yearly double-digit growth, and nationwide availability in nearly 20,000 natural food stores and in three out of four major retailers (United States Department of Agriculture – Economic Research Service, 2016), organic production has become a major agricultural and economic sector in the United States. Weed control has been identified as one of the primary challenges in organic production (i.e. Tautges et al., 2016). The management of annual weeds in agricultural settings has improved with ecologically-based tactics such as the development of competitive crop genotypes to enhance weed suppression, the integration of multiple management tactics, and the tailoring of management strategies to the temporal and spatial variability of weed populations (Liebman et al., 2016). Yet, organic producers continue to struggle to manage perennial rhizomatous weeds. For example, in recent surveys administered to both agricultural stakeholders and academic researchers, perennial rhizomatous weeds such as field bindweed (*Convolvulus arvensis* L.) and Canada thistle [*Cirsium arvense* (L.) Scop] were specifically acknowledged as obstacles to organic production (OAEC, 2013a, 2013b; Tautges et al., 2016). These species threaten the economic and environmental sustainability of organic enterprises, and developing methods to reduce their spread and impact has been identified as a research priority by organic grain and vegetable growers as well as researchers (DeDecker et al., 2014; Tautges et al., 2016).

Perennial rhizomatous weeds have been difficult to manage in agronomic systems since prehistoric times (Hakansson, 2003a) and were of major concern in Great Plains cropping systems prior to the introduction of synthetic herbicides (i.e. Blankenship, 1901). While these species can be managed with synthetic herbicides, the recent expansion of organic agriculture (United States Department of

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Agriculture – Economic Research Service, 2016) has resulted in a concomitant increase in impact and management concerns related to these species. A main reason for the difficulty in managing perennial weeds in organic systems resides in their biological characteristics. The extensive and persistent underground root system of many perennial species is extremely difficult to manage using organic methods as their carbohydrate reserves provide them with the ability to resist many management techniques used in these types of systems (e.g. regrow after tillage or grow through mulch) and a competitive advantage over crops or other desired vegetation (Bakke et al., 1939; Mohler, 2001b; Nadeau and Vanden Born, 1990). In established stands, the portion of the roots used for carbohydrate storage occurs below soil horizons impacted by tillage, meaning that successful management of these types of species by organic methods requires depletion of these deep root reserves (Mohler, 2001b).

Researchers and organic producers have explored approaches to manage field bindweed and Canada thistle without synthetic herbicides over many decades, but there is no current consensus on best management practices. Historically, the most commonly recommended method for achieving control of these species was through repeated plowing or cultivation applied as often as every one or two weeks, which even led to eradication in some cases (i.e. Hodgson, 1958; Timmons, 1941; Tingey, 1934). While successful in terms of weed control, these studies did not evaluate the economic returns or potential negative environmental consequences of frequent tillage which can result in soil erosion by wind and water, soil moisture storage concerns, and nutrient leaching (Hakansson, 2003b; Parr et al., 1992). However, more recent studies have focused on reducing reliance on tillage by integrating practices that increase crop competitive ability with the goal of depleting carbohydrates stored in the root systems of these weeds (i.e. DallArmellina and Zimdahl, 1988; Lukashyk et al., 2008). Additional approaches to managing these species in organic systems include integrating crop rotation, targeted grazing, solarization, and in some cases biological control (Hakansson, 2003a). To date, no formal study has systematically evaluated the existing literature to assess the effectiveness of these and other methods.

When grappling with difficult issues in agriculture, it can be useful to consult and synthesize findings from previously published literature. One way to accomplish this is through meta-analysis, or the process of statistically merging results of previous research to answer new questions of interest (Gurevitch and Hedges, 2001). The issue of perennial weed management in organic systems is a good fit for meta-analysis as the problem has been identified by agricultural producers and researchers for many years, so there is a substantial amount of information available to synthesize about the topic. A meta-analysis approach has been used to synthesize information in many agronomic topics; Philibert et al. (2012) reported that at the time of their publication five meta-analyses had been conducted targeting pests in agronomic systems. These types of studies are useful for making generalizations about management options, as well as for identifying possible knowledge gaps that exist in the literature (Koricheva and Gurevitch, 2014).

There is a need to systematically evaluate single and integrated approaches to control field bindweed and Canada thistle in the absence of synthetic herbicides. We undertook meta-analyses of the existing literature to 1) identify promising organic management approaches for field bindweed and Canada thistle and 2) determine which aspects of field bindweed and Canada thistle organic management warrant further study.

2. Materials and methods

2.1. Literature search

For the initial literature review, we conducted two searches, one for field bindweed and one for Canada thistle. For the field bindweed search, we searched the Web of Science® (1864–2014) and Agricola® (1970–2014) databases using the Latin binomial, "*Convolvulus arvensis*," and common names, "field bindweed," "creeping jenny," and "perennial morning glory." For the Canada thistle search, we searched the Web of Science® (1864–2014) and Agricola® (1970–2014) databases for the terms "*Cirsium arvense*," "*Carduus arvensis*," "Canada thistle," "creeping thistle," "Californian thistle," and "field thistle." We limited searches to papers written in English. We conducted these searches in November 2014, compared resulting databases, and removed duplicated studies.

Records obtained during the initial literature search were systematically screened following Koricheva and Gurevitch (2014) to determine their suitability for our study based on three main criteria: 1) management techniques that did not include synthetic herbicides were applied to field bindweed or Canada thistle and were compared to non-treated groups (i.e. only designed experiments that included a control were included and observational studies were omitted); 2) experiments were conducted in a field setting (i.e. greenhouse studies were not included), and 3) studies measured a change in aboveground abundance or survival of field bindweed or Canada thistle (i.e. percent cover, density, biomass, and percent control) in response to a treatment. In addition, since our study was meant to inform perennial weed management in organic systems, synthetic herbicides could not have been applied to experimental units of interest at any point during a study. It is important to note that we did not require studies to be conducted in certified organic systems in order to be included. For example, synthetic herbicides could have been applied to some of the plots in a given study, but we required at least one comparison between a non-herbicide management tactic and a non-treated control for a paper to be included in our analyses. Finally, studies were excluded if synthetic herbicides were used as site preparation in all experimental units.

Studies conducted in all agronomic systems and geographic areas were included. Records were subjected to a number of filters to identify studies appropriate for our questions of interest based on the criteria described above (Fig. 1a and b). Titles and abstracts of all studies were screened, and those that did not meet our criteria were omitted. The full text of the remaining articles was then assessed for inclusion in the study. All literature screening and review was conducted by the same author (Noelle Orloff).

2.2. Data extraction

There were several potential sources of non-independence in our data set. Following Gurevitch and Hedges (2001) we mitigated their potential impact in this study by developing pre-determined criteria to define which data points to extract from each article. For example, for studies that reported results over several time points (i.e. repeated-measures studies), we extracted data from the last reported time. Similarly, for studies that reported results for multiple levels of a factor, we extracted data from the highest factor level (i.e. highest concentration of bioherbicide, closest row spacing, greatest number of tillage events, etc). When the highest level of the factor was not obvious, we pooled levels of the factor (i.e. variety trials, ecotypes of weeds). If studies were replicated across more than one location or multiple trials were conducted at the same location, we considered the responses independent in each location and trial.

Retaining more than one response variable for a given experimental unit also introduces problematic pseudo-replication to meta-analyses (Gurevitch and Hedges, 2001). In 21% of studies selected for analysis, there were two or more response variables reported for the same experimental unit. To reduce potential bias, if two abundance response variables were reported for the same experimental unit in the same study, we selected the response we considered most useful for describing perennial weed abundance in agroecosystems. To achieve this goal, and based on the life history and growth habit of field bindweed and Canada thistle, we extracted response variables in a pre-determined order of importance (biomass > percent canopy cover > density >