A systematic review of field bindweed (*Convolvulus arvensis*) control and management studies in organic and diversified cropping systems for the Northern Great Plains region

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Executive Summary

One of the greatest challenges to the long-term sustainability of organic agriculture in the Northern Great Plains (NGP) is perennial weed management. Organic producers in Montana have identified field bindweed (*Convolvulus arvensis*) management as a specific challenge. Despite the variety of potential mechanical and cultural management techniques available to control field bindweed, producers continue to struggle with it in organic systems. We systematically reviewed previous research to determine which aspects of non-chemical field bindweed management warrant further study and highlight best management practices for its control.

Our literature search revealed that very little research has been conducted about non-chemical management of field bindweed in the NGP. Only five studies out of the 48 that met our criteria for inclusion in the study were conducted in this region. However, in looking at literature from the rest of the world, we were able to delineate research areas that seem promising and highlight management practices that could be considered by growers in our region. Our main research findings from the systematic review were:

- Overall, integrated management, where two or more control methods are combined to manage field bindweed, holds the most promise. In annual cropping systems, integrated management in the NGP would be an excellent area for future on-farm research, especially if studies included a form of mechanical control combined with a competitive crop or cover crops in the study design.
- Intensive cultivation can control field bindweed in agricultural systems, but this may not be a method that producers across the NGP may be willing to undertake because it is expensive and decreases soil health. The most interesting and potentially useful aspect of

mechanical control is how it can be integrated with other methods.

- It would be beneficial to investigate if intercropping methods are effective in Montana, and which might work best within the climatic constraints of the NGP.
- Research about the most effective cover crop species and varieties for managing field bindweed in the NGP would be useful.
- Mulching for field bindweed management in either annual or perennial systems would be an interesting focus for future research, as there is little information about this method in the NGP, but studies suggest it is effective in other parts of the world.
- For perennial systems such as pasture and hay fields, research that focuses on increasing or sustaining the competitive ability of crops or other desired plants may be the most useful for field bindweed management. Possibilities include research about competitive species or cultivars, cover crops, and fertilizing or mowing regimes.

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Introduction

Management of perennial weeds is one of the greatest challenges to the long-term sustainability of organic agriculture in the Northern Great Plains (NGP) and identifying methods of reducing the spread and impact of field bindweed has been identified as a priority by organic grain and vegetable growers (Grisak, 2012; OAEC, 2013). In Montana alone, 30,000 acres of organic grain production were taken out of production in 2010-2011, due in part to the difficulty of managing this species (Grisak, 2012). The need to find approaches to successfully manage field bindweed is growing as current management tactics are not effective and producers need information regarding effective or promising management strategies. In fact, in a survey of organic growers conducted by the OAEC 85% of respondents categorized field bindweed as being either “Hard” or “Impossible” to control, and respondents also identified field bindweed control as the weed issue where research is most needed (OAEC, 2013).

Previous research has explored different approaches to organic field bindweed control, but to our knowledge no clear solutions or recommendations exist. One commonly recommended method of controlling this weed is repeated tillage (i.e. Hodges, 2003), but relying solely on mechanical control tactics in the relatively dry ecosystems of the NGP is not feasible due to erosion and soil moisture concerns, as well as economics. Cultural practices such as the use of competitive crops can be useful for field bindweed management due to its sensitivity to shading (Bakke, 1939; Dall’Armellina and Zimdahl, 1988). Additional approaches to managing this species in organic systems include the use of cover crops and crop rotation, and possibly targeted grazing and biological control. Despite the variety of potential management techniques available to control field bindweed, producers continue to struggle with it in organic systems and a systematic review of the existing literature may highlight promising management approaches and research areas where knowledge gaps exist.

The first objective of this project was to quantify and compare the efficacy of different management practices carried out on field bindweed in organic and diversified cropping systems. We also sought to determine which aspects of field bindweed management require further study. Thoroughly reviewing and quantitatively assessing the information available about managing this species will not only help the OAEC determine what aspects of field bindweed management warrant further study, but will also highlight current best management practices for its control, and provide ideas to improve its management.

Methods

Literature Search

For the initial literature search, our intent was to be inclusive. We searched the Web of Science® (1864-2015) and Agricola® (1970-2015) databases for the terms "*Convolvulus arvensis*," "field bindweed," "creeping jenny," and "perennial morning glory." We limited our search to papers written in English.

Systematic Review

Studies were included in the next step of the analysis if non-chemical management techniques were applied to field bindweed in a field setting (i.e. greenhouse studies were not included), regardless of the agronomic systems or geographic areas where the study was conducted. Included papers also had measurements for a change in abundance of field bindweed in response to a control method. These measurements included percent cover, density, biomass, and percent control.

Quantitative Analysis

Our original objective, as stated in our proposal to the OAEC, was to conduct a formal meta-analysis of field bindweed management. However, most of the articles we found did not report measures of variability such as standard error or standard deviation, and these measurements are needed to perform required steps of formal meta-analysis. Variability is the extent to which data points differ from one another. For example, if a control measure is tested on three different fields, variability would be the extent to which results from each field are different than the average across all three fields. To summarize information from all field bindweed studies that met our search criteria, *we instead conducted a quantitative summary analysis rather than a formal meta-analysis* (Pullin and Stewart 2006). This approach requires that we have means (i.e. averages), but not estimates of variability. In a true meta-analysis, we would use the measures of variability to weight mean field bindweed responses to treatments, whereas in this report we use unweighted means. Using this approach, we may misrepresent true means if they have high variability, but we considered this a small risk compared with biasing our analysis by using only the few articles available that did report measures of variation.

Table 1. Treatment categories used to conduct a quantitative analysis of non-chemical field bindweed management tactics.

Management Categories	*Description*
Biocontrol	Biological control with insects or pathogens
Bioherbicide	Plant extract used as bioherbicide
Competition	Any method attempting to increase crop competitive ability including ridge sowing, manipulating row spacing, intercropping, revegetation, and trials with competitive species or cultivars
Crop Diversification	Adding cover crops or increasing crop rotation to a cropping system
Flaming	Flame weeding using propane torch
Flooding	Inundating with water
Grazing	Using animals to graze bindweed
Integrated	Any combination of two or more control methods.
Mechanical	Any mechanical control method including hand or mechanical hoeing, handweeding, or cultivation
Mowing	Mowing the site
Mulch	Use of either plastic or organic mulches
Reduced Tillage	Impact of reduced tillage intensity on field bindweed control
Shading	Reduction in light availability using shade cloth
Soil Amendments	Soil amendments including manure or fertilizer applied
Solarization	Heating the soil by using dark or translucent plastics

To begin the analysis, we first identified fifteen treatment categories used in the selected studies to manage field bindweed (Table 1). We also separated studies conducted in annual systems (row crop, fallow, etc.) from those conducted in perennial systems (pasture, hay, natural areas, etc.). In order to compare these studies to one another, we first had to take the reported data and calculate an effect size for each one. An effect size is an index that measures the size of a treatment effect by comparing a treated group to a non-treated group. We used the response ratio (RR) as an effect size (Goldberg et al 1999), and calculated it for each field bindweed measurement as:

RR = natural log(mean for an experimental group/mean for non-treated group)

We then calculated an average effect size for each treatment category in Table 1. We also calculated 95% confidence intervals for each of these averages as: mean $\pm$ 1.96($\sigma/\sqrt{n}$). Here, σ is standard deviation and n is the sample size. *Negative effect sizes indicate a reduction in field bindweed abundance, while positive effect sizes indicate an increase*. We considered effect sizes to be different from zero if their confidence intervals did not overlap zero and effect sizes were different from one another if confidence intervals did not overlap (Gurevitch et al 1992).

Results and Discussion

Literature Search

Our initial literature search yielded 1280 papers. We then screened titles and abstracts of those studies, and performed a full-text review of 232 papers. As a result of the screening we collected 48 papers that met the criteria stated above, and we used these papers for our analysis (Fig. 1). Of these, 33 were conducted in annual systems, 20 were conducted in perennial systems, and six were conducted in both annual and perennial systems. The appendices include two tables outlining the specifics of each paper used in the analysis including authors, date of publication, duration of study, and average effect sizes for each management technique used in each paper. Appendix 1 includes studies focused on annual systems, while Appendix 2 lists papers about perennial systems.

A few key observations can be drawn from the literature found during this search and filtering process (Appendix 1 and 2). The first is that very little research has been done on non-chemical field bindweed management in the NGP, defined as the area bordered by Nebraska on the south, the western boundary of Montana, the eastern boundaries of North and South Dakota, and the northern edge of cultivation in western Canada (Blade et al 2002). Specifically, only five papers out of 48 in the analysis were conducted in this region. Another is that most of the studies we used in the analysis are short term studies lasting one or two years. As field bindweed is a perennial species with an extensive root system, mid- and long-term research is needed to determine effective control strategies.

Quantitative Analysis; Annual Systems

Four broad groups of control methods can be delineated in annual systems based on the results of the analysis (Fig. 2). Integrated management, which we defined as the combinations of two or more control methods being used on field bindweed over the course of one study, caused the largest relative decrease in this species' abundance and is thus the most promising control method. The next best group of field bindweed control methods included biocontrol, competition, crop diversification, mechanical control, mulch, and solarization, with similar effectiveness to one another. Bioherbicide did not make a difference in bindweed abundance, and reduced tillage and soil amendments increased bindweed abundance. We will discuss the methods that decreased field bindweed abundance below.

Integrated: A closer inspection of the most promising approach to field bindweed control revealed that of the four integrated control studies, three are from 1950 or earlier, and they all investigated intensive cultivation followed by competition from competitive crops. These studies had some of the lowest effect sizes of any included in the analysis (Appendix 1). In multi-year studies, Stahler (1948) and Wilson et al (1942) both explored intensive cultivation followed by seeding a variety of competitive crops including corn, hemp, millet, sorghum, soybeans, and sudangrass in Minnesota, which led to field bindweed reductions of 90% to 99%. Timmons (1950) reported results of cultivation combined with closely seeded sorgo in Kansas and reduced field bindweed by 67% over four years. In a more recent study, Bilalis et al (2003) investigated minimum tillage combined with mulch in a fava bean crop for one year, leading to a 79% decrease in field bindweed. Integrated management of field bindweed in annual cropping systems in the NGP appears to be an excellent area for future on-farm research, especially if studies included a form of mechanical control combined with a competitive crop or cover crops in the study design. However, future studies should also incorporate the potential impacts of soil cultivation on soil health.

Competition and Crop Diversification: After integrated management, we view competition and crop diversification to be the next most promising areas for further research on bindweed control in the NGP. Each of these categories was represented by four studies in our analysis. For competition, the four studies were conducted in corn, cotton, or wheat-sorghum-tilled fallow cropping systems and included intercropping, decreased row spacing, ridge sowing, and sowing competitive species. Unfortunately, none of the crop competition studies were conducted in the NGP. The method that led to the largest decrease in field bindweed in the competition category was intercropping squash with corn in California, which led to a field bindweed decrease of 72% over three years (Fujioshi et al 2007). Based on these results, we believe it would be beneficial to investigate if intercropping methods are effective in Montana, and which might work best within the climatic constraints of the NGP.

The four crop diversification studies focused on several different cover crops and a variety of crop rotations. The largest decrease in field bindweed was observed in a study comparing various crop rotations to continuous corn in South Dakota, which led to a 98% reduction in field bindweed over two years (Franzke et al 1936). Also in South Dakota, Dercheid (1978) observed field bindweed decreases of 74% to 90% as a result of cover cropping with millet, sorghum, soybeans, or sudangrass for three years. Research building upon Dercheid (1978) about the most effective cover crop species and methods for field bindweed management in the NGP would be beneficial.

Biocontrol: An inspection of the four biocontrol studies which investigated the use of fungal pathogens *Phoma proboscis* and *Phomopsis convovulus* and defoliating insect *Galeruca rufa* indicated that applying biocontrol to field bindweed in the field can decrease its abundance. However, this control method is impractical at this time as these three biological control agents are not available in the U.S.

Mechanical Control: Mechanical control used as a single control method has been well-researched with 15 studies used in our analysis focusing on it. The studies used in our analysis included mouldboard ploughing, harrowing, sweep cultivation, rotary hoeing, and hand hoeing. It is clear from several papers that intensive cultivation can control field bindweed (i.e. Timmons 1941, Dercheid et al 1970, Lanini and Miyao 1989), with some studies implementing cultivation every five days for two years, and others implementing one cultivation per year. The lowest effect size for mechanical control of field bindweed was from Lanini and Miyao (1989), where four cultivations were implemented by tomato growers at two-week intervals, leading to a 99% field bindweed decrease after one year. Intensive cultivation alone may not be a method that producers in our region should undertake because it is expensive and decreases soil health, but it can be an effective means of controlling field bindweed. Since there has been substantial research on mechanical control of field bindweed, the most interesting aspect of mechanical control for future research is how it can be integrated with other methods as described above, with particular emphasis on soil health and erosion.

Solarization: Solarization was only represented by two studies and though no solarization studies have been conducted in the NGP, it appears to be effective in other areas of the U.S. The two studies about solarization included in our analysis were both from California and were implemented in relatively small-scale systems. Elmore et al (1993) applied a clear tarp to fallow areas for nine weeks leading to 81% reductions in field bindweed, while Zasada et al (2003) applied a clear tarp for six weeks leading to 16% to 57% reductions in field bindweed. Both studies achieved a decrease in field bindweed abundance in short-term experiments, but they only reported field bindweed response after one year. Solarization may be a promising method of field bindweed control, particularly if integrated with competitive crops or cover cropping after the solarization period. However, while it could be adopted in small-scale operations, it is unlikely that it could be implemented on a large scale.

Mulch: The three studies assessing mulching for field bindweed management suggest that it may be a promising focus for future research, particularly since no mulching studies have been carried in the NGP. Two studies were carried out in Greece using wheat straw or barley straw as mulch, and one was conducted in Pakistan assessing wheat straw mulching in fava bean, leek, and cotton systems. The greatest reduction in field bindweed was in a fava bean crop in Pakistan, where researchers implemented a 90% mulch cover of wheat straw that led to an 81% decrease in field bindweed abundance (Bilalis et al 2003). Research about adapting this method for use in the NGP could be useful for future field bindweed management.

Quantitative Analysis: Perennial Systems

We found fewer studies that were conducted in perennial systems compared with annual systems. There were studies in 12 of our 15 treatment categories, but many of them only had one study in the category so it is difficult to make inferences or generalizations about them. In addition, most of the confidence intervals for the categories overlapped with one another, indicating that they each had similar effects on field bindweed abundance. However, our results highlight specific ideas for field bindweed management and research that we can draw from our systematic literature review.

The studies we used in our quantitative summary analysis can be broadly broken into three groups of field bindweed management strategies (Fig. 3). The studies with largest decrease in field bindweed abundance in perennial systems focused on shading and flaming as control methods. The group that had intermediate decreases in field bindweed abundance included biocontrol, competition, crop diversification, flooding, integrated management, mechanical control, mulch, and soil amendments. Finally, grazing and mowing were represented by one and two studies, respectively, and they did not affect field bindweed abundance.

Flaming and Shading: While these two control tactics had the largest impact on field bindweed, both shading and flaming were only investigated in one study. Bakke and Gaessler (1945) shaded small plots of field bindweed with different types of cloth that had different light transmission values. Shading the field bindweed decreased its abundance by 76% to 99% for the one year that the study was conducted. This method may be an interesting opportunity for future research in small scale systems. In the one year flaming study conducted by Ulloa et al (2010) in Nebraska, researchers observed 92% to 96% decreases in field bindweed abundance as a result of broadcast propane flaming. However, since this method does not impact the extensive root system, it may not be a good long-term solution for field bindweed management.

Biocontrol (with *Sclerotina minor* fungus, *Stagonospora convolvuli* fungus, *Tyta luctuosa* moth, or *Galeruca rufa* beetle), competition, crop diversification, flooding, integrated management, mechanical control, mulch, and soil amendments all decreased field bindweed abundance. Of these, competition, crop diversification, integrated management, mechanical control, mulch, and soil amendments may be the most promising for use in the NGP. As with the annual system studies, biocontrol of field bindweed appears to be impractical at this time due to the agents either being unreliable or not commercially available. Flooding is also probably an impractical control method in our dryland agricultural systems.

Competition, Crop Diversification, Integrated Management, and Soil Amendments: Competition was represented in our quantitative summary analysis by four studies, but the relatively large decrease in field bindweed abundance for this method was mostly driven by one study in particular; Dercheid (1978) had field bindweed decreases of 49% to 97% after four years as a result of sowing various forage crops such as alfalfa, smooth brome, and intermediate wheatgrass in South Dakota. In the soil amendments category there was one study that tested adding fertilizer to a permanent grassland. This led to a 51% decrease in field bindweed abundance, possibly due to the fertilization increasing the competitive ability of desired vegetation (Benizri and Amiaud 2005). Only one study explored crop diversification in perennial systems, where researchers observed field bindweed decreases of up to 60% over a three year period after planting rye or triticale cover crops in a vineyard in California (Baumgartner et al 2010).

Integrated methods of field bindweed control in perennial systems were explored in four studies. The study that had the largest decrease in field bindweed abundance implemented cultivation followed by seeding an alfalfa stand, leading to a 98% decrease during a one year study (Rosenthal and Hostettler 1980). Timmons (1950) conducted another integrated management study in a pasture setting where he sowed various forage grasses (buffalograss, bentgrass, or bermudagrass) while implementing different mowing and watering regimes, and these methods decreased field bindweed abundance by 88% to 94% over four years. Our systematic review of the existing literature suggests that for perennial systems, research that focuses on increasing or maintaining the competitive ability of the crop or other desired plants may be the most useful for future bindweed management.

Mechanical: Mechanical control was attempted in four studies collected in our quantitative summary analysis. Mechanical methods included hand weeding, hand hoeing, mechanical hoeing, and shallow disking. These methods all decreased bindweed abundance, with the largest reduction seen in studies implementing shallow disking which led to an 88% reduction (Taylor and Smith 2003) and repeated hand pulling which led to an 82% reduction (Kinch and Keim 1937). As we observed in annual systems, mechanical control research will be most interesting and informative if it is integrated with methods that increase the competitive ability of remaining desired vegetation, and care should be taken to reduce the risk of soil erosion.

Mulch: Mulching treatments were quite effective in the only study in which this technique was investigated in a perennial system. Researchers mulched with black polyethylene or rice straw in an orange orchard in Egypt, and reported decreases in field bindweed abundance of 91% and 86%, respectively over a two year period (Hassan et al 2006). If producers and researchers can determine a viable mulching technique to use in the NGP, it may be useful for bindweed management in perennial systems.

Overall conclusions

Overall, integrated management appears to be the most promising method of field bindweed control. Cover cropping, crop rotation, mechanical control, mulching, shading, and solarization also show promise. While these techniques appear to be promising for field bindweed management in annual and perennial organic and diversified systems, two major issues hinder the strength of our observations. First, most of the studies included in our analysis were carried out over a relatively short time period of one or two years. We need longer-term research to better understand how each control method impacts this long-lived perennial weed. Second, there have not been enough studies conducted for each treatment method to draw strong conclusions about their efficacy, particularly in perennial systems.

Recommendations for Future Research

- Integrated management of field bindweed in annual cropping systems in the NGP would be an excellent area for future on-farm research, especially if studies included a form of mechanical control combined with a competitive crop or cover crops in the study design. These studies should consider the mid- and long-term impact of management practices on field bindweed abundance and spread as well as soil health.
- It is clear that intensive cultivation can control field bindweed in agricultural systems, but this may not be a method that producers across the NGP may be willing to undertake because it is expensive and decreases soil health. The most interesting and potentially useful aspect of mechanical control is how it can be integrated with other methods.

- It would be beneficial to investigate if intercropping methods are effective in Montana, and which might work best within the climatic constraints of the NGP.
- Research about the most effective cover crop species and methods for field bindweed management using cover crops in the NGP would be useful.
- Mulching for field bindweed management in either annual or perennial systems represents an interesting focus for future research, as there is little information about this method in the NGP, but previous studies suggest it is effective in other parts of the world.
- For perennial systems, research that focuses on increasing or sustaining the competitive ability of crops or other desired plants may be the most useful for field bindweed management. This could include research about competitive species or cultivars, cover crops, and fertilizing or mowing regimes.
- Most research on field bindweed has been over a one or two year period. As field bindweed is a perennial species with an extensive root system, long-term research is needed to determine which control strategies might be effective over many years.
- Many interesting methods that would fit into this list are certainly already being implemented by growers in the NGP, and it would be useful to find out what is already looking promising in our region as a preliminary step to further field bindweed management.

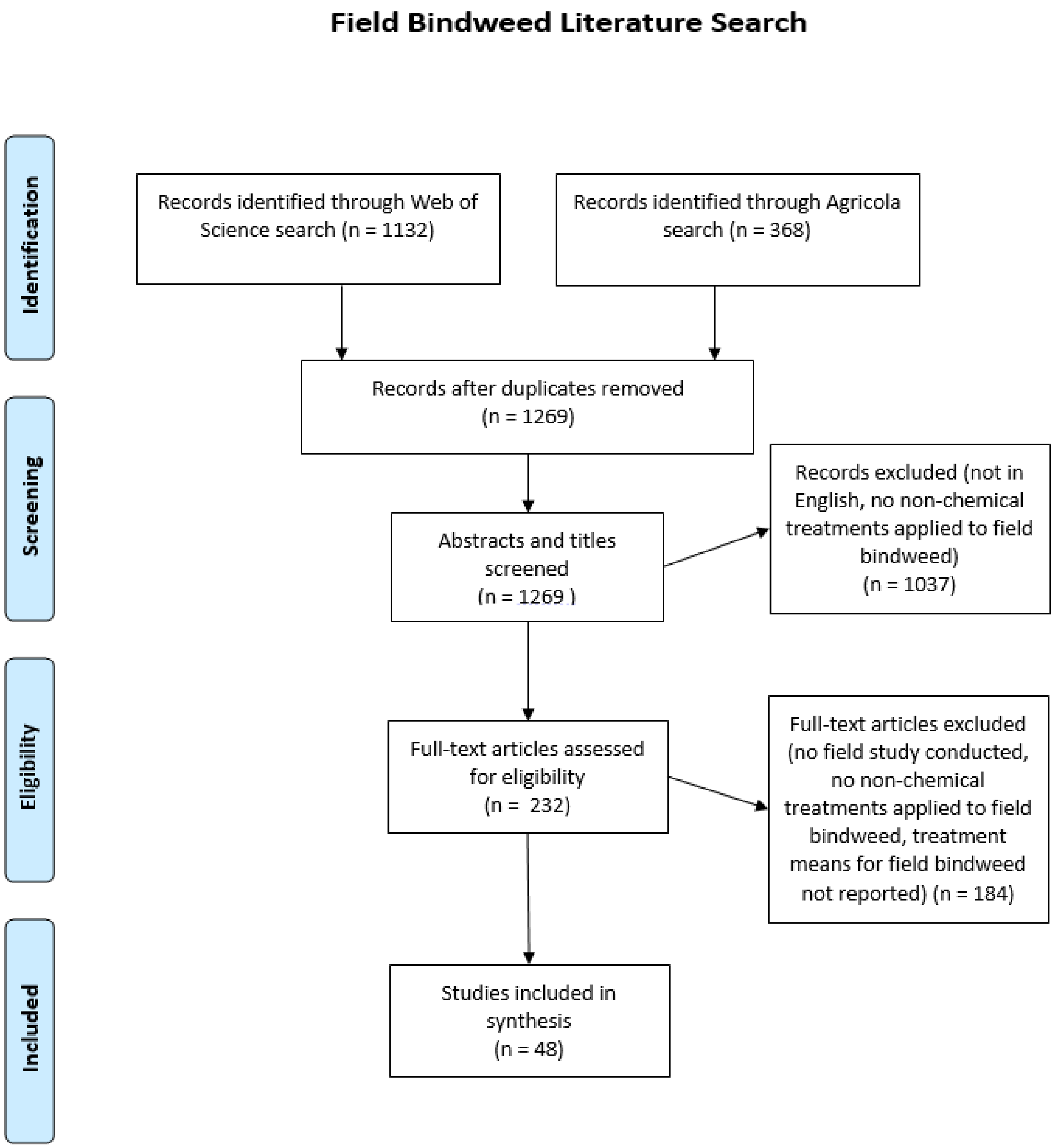

Figure 1. Flow chart showing the steps taken during literature screening portion of the systematic review of non-chemical field bindweed control. In each box, n is the number of records described in that step.

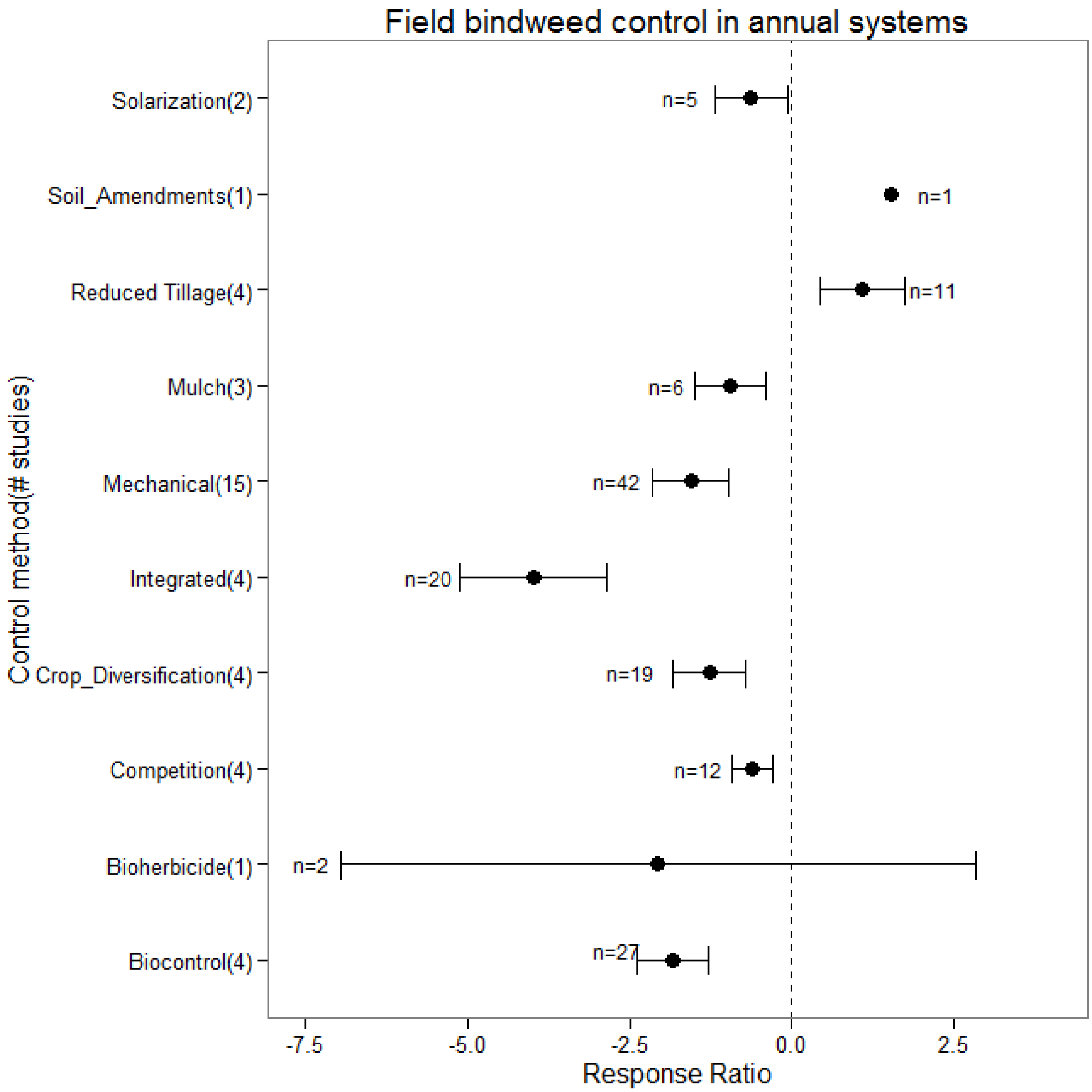

Figure 2. Mean effect sizes, or response ratios (points) and 95% confidence intervals (lines and brackets) for non-chemical field bindweed control in annual cropping systems. *More negative means correspond with a greater decrease in bindweed abundance*. Control methods decrease bindweed abundance if the confidence intervals do not cross zero (dotted line). They are different from one another if confidence intervals do not overlap. For each method, n is the number of observations that was used to calculate the mean, and the number in parentheses after control methods on the y-axis is the number of studies that covers each method.

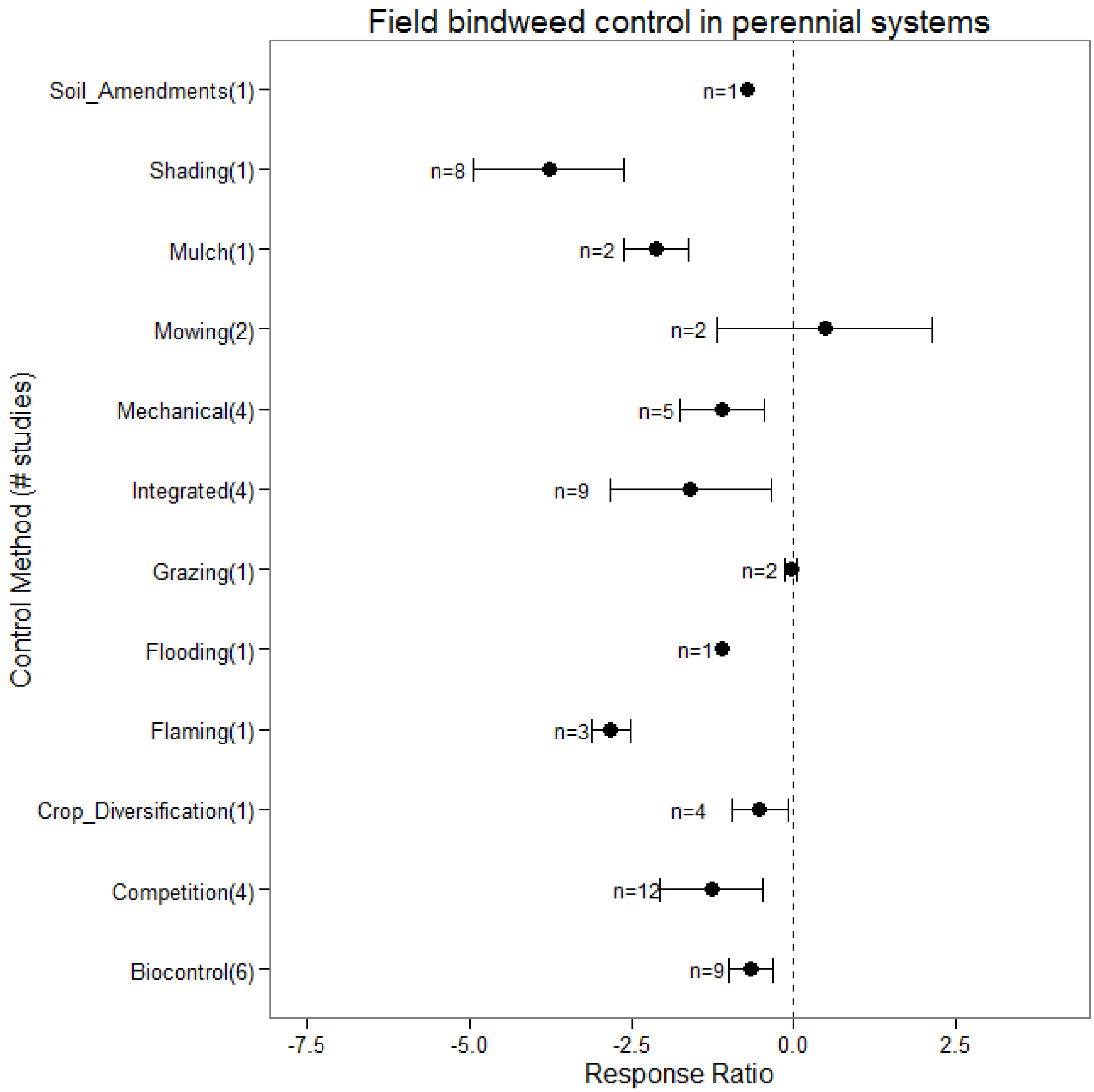

Figure 3. Mean effect sizes, or response ratios (points) and 95% confidence intervals (lines and brackets) for non-chemical field bindweed control in perennial systems. *More negative means correspond with a greater decrease in bindweed abundance*. Control methods decrease bindweed abundance if the confidence intervals do not cross zero (dotted line). They are different from one another if confidence intervals do not overlap. For each method, n is the number of observations that was used to calculate the mean, and the number in parentheses after control methods on the y-axis is the number of studies that covers each method.

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Appendix 1: Studies used in systematic review and quantitative analysis of non-chemical field bindweed control in annual systems.

CITATION	STUDY LOCATION(S)	STUDY DURATION	CROPPING SYSTEM/PHASE	INTERVENTION UNDER INVESTIGATION	INTERVENTION CATEGORY	MEAN EFFECT SIZE
BAKKE ET AL 1939*	Iowa, USA	2 years	Fallow/cover crop	Cane, corn, millet, soybeans, sudangrass, or cane cover crop for two years	Crop Diversification	-0.018
			Fallow	Cultivated every 5 days for 1 or 2 years	Mechanical	-0.192
BILALIS ET AL 2003	Athens, Greece	1 year	Fava bean row crop	Minimum tillage combined with mulch	Integrated	-1.335
				Minimum tillage (two passes of rotary hoe)	Mechanical	-0.061
				Greater than 90% cover of wheat straw mulch	Mulch	-1.556
DERCHEID ET AL 1970	Presho, South Dakota	4 years	Wheat, sorghum, fallow rotation	Intensive cultivation	Mechanical	-3.829
DERCHEID 1978	Scotland, South Dakota	4 years	Fallow/cover crop	German millet, proso millet, sorghum, soybeans, or sudangrass cover crop for three years	Crop Diversification	-1.944
ELMORE ET AL 1993	Davis, California	1 year	Fallow	Solarization with clear tarp for 9 weeks	Solarization	-0.865
ERMAN ET AL 2004	Van, Turkey	2 years	Lentil	Hand hoeing twice a year	Mechanical	-0.127
FATHI 2006	Khoozestan, South Iran	2 years	Common bean	One or two cultivations	Mechanical	-1.153
FRANZKE ET AL 1936	Brookings, South Dakota	2 years	Various crop rotations and phases	Various crop rotations used and compared with corn continuous crop	Crop Diversification	-2.371
FUJIOSHI ET AL 2007	California, USA	3 years	Corn	Intercropping with squash	Competition	-1.27

*Citations in italics are studies that were conducted in both annual and perennial systems and are included in both Appendix 1 and 2.

Appendix 1: Studies used in systematic review and quantitative analysis of non-chemical field bindweed control in annual systems.

CITATION	STUDY LOCATION(S)	STUDY DURATION	CROPPING SYSTEM/PHASE	INTERVENTION UNDER INVESTIGATION	INTERVENTION CATEGORY	MEAN EFFECT SIZE
GARCIA-MARTEN ET AL 2007	Badajoz, Spain	2 years	Four year rotation: Fallow- barley- vetch green manure-wheat	Inter-row hoeing	Mechanical	-0.981
				Harrowing	Mechanical	-0.288
HEINY 1994	Colorado and Arkansas, USA	2 years	Fallow	*Phoma proboscis* fungal biocontrol	Biocontrol	-0.913
HEISEY AND HEISEY 2003	Pennsylvania, USA	1 year	Row crops- various from radish to tomato to oats	*Ailanthus altissima* stem bark extract	Bioherbicide	-2.066
KARKANIS ET AL 2012	Athens, Greece	2 years	Leek	Mulch: 6 tons/hectare barley straw	Mulch	-0.243
KATARIA AND KUMAR 1981	Hissar, India	2 years	Irrigated dwarf wheat	Hand weeding twice	Mechanical	-0.693
KHALIL ET AL 2010	Peshawar, Pakistan	1 year	Corn intercropped with various species	Intercropping with mungbean, sunflower, or sorghum	Competition	-0.996
				Decrease row spacing from 95 to 75 cm	Competition	-0.145
KISMANYOKY ET AL 2007	Keszthely, Hungary	22 years	Three year rotation: Maize- winter wheat-winter barley	NPK + farmyard manure	Soil Amendments	1.549
LANINI AND MIYAO 1989	California, USA	1 year	Tomatoes	Four cultivations in two week intervals	Mechanical	-5.236

*Citations in italics are studies that were conducted in both annual and perennial systems and are included in both Appendix 1 and 2.

Appendix 1: Studies used in systematic review and quantitative analysis of non-chemical field bindweed control in annual systems.

CITATION	STUDY LOCATION(S)	STUDY DURATION	CROPPING SYSTEM/PHASE	INTERVENTION UNDER INVESTIGATION	INTERVENTION CATEGORY	MEAN EFFECT SIZE
LEHOCZKY ET AL 2009	Keszthely, Hungary	1 year	Crop rotation: wheat-winter wheat- maize-maize	Reduced tillage (disc tillage or no-till drill) compared with plowing	Reduced tillage	1.828
MARWAT ET AL 2007	Peshawar, Pakistan	1 year	Maize	Reduced tillage compared with conventional tillage	Reduced tillage	0.575
NADEEM ET AL 2013	Faisalabad, Pakistan	2 years	Cotton	Ridge sowing	Competition	-0.055
				Hand hoeing	Mechanical	-0.348
				Mulch: 6 tons/hectare wheat straw	Mulch	-0.539
ROSENTHAL AND HOSTETTLER 1980	Rome, Italy	1 year	Fallow	*Galeruca rufa* (insect) defoliation	Biocontrol	-0.472
RUSU ET AL 2006	Cluj-Napoca, Romania	4 years	Five crops: Soybean, wheat, potato, spring rape, and corn.	Various minimum tillage techniques compared with "classic" tillage (plow + disk)	Reduced tillage	0.282
SANS ET AL 2011	Frank, Switzerland	3 years	Organic row crops: winter wheat, sunflower, and spelt	Reduced tillage (chisel plow + rotary harrow) compared with conventional tillage (mouldboard plow)	Reduced tillage	1.085
SINGH AND AGARWAL 2004	Hisar, India	2 years	Dryland mustard	Hand hoeing	Mechanical	-0.721
STAHLER 1948	Minnesota, USA	3 years	Tested crops including soybeans, millet,	Intensive cultivation until July 1, followed by seeding hemp, millet,	Integrated	-4.707

*Citations in italics are studies that were conducted in both annual and perennial systems and are included in both Appendix 1 and 2.

Appendix 1: Studies used in systematic review and quantitative analysis of non-chemical field bindweed control in annual systems.

CITATION	STUDY LOCATION(S)	STUDY DURATION	CROPPING SYSTEM/PHASE	INTERVENTION UNDER INVESTIGATION	INTERVENTION CATEGORY	MEAN EFFECT SIZE
			sorghum, sudangrass, hemp, and oats	rye, sorghum, soybeans, sudangrass, or wheat.		
TIMMONS 1941	Kansas, USA	4 years	Kafir, rye, or wheat row crops	Tilled fallow phase added to continuous kafir, rye, or wheat	Mechanical	-3.67
TIMMONS 1949	Kansas, USA	9 years	Rotation: winter wheat- sorghum-summer fallow	Wheat and kafir crop rotation	Crop Diversification	0
				Close-drilled sorgo combined with cultivation	Integrated	-0.791
				Intensive cultivation; from 33 to 54 cultivations depending on crop tested	Mechanical	-1.666
VOGELSGANG ET AL 1998 (A)	Quebec, Canada	2 years	Fallow	*Phomopsis convolvulus* (pathogen) application	Biocontrol	-2.981
VOGELSGANG ET AL 1998 (B)	Quebec, Canada	2 years	Fallow	*Phomopsis convolvulus* (pathogen) application	Biocontrol	-2.349
WIESE AND RHEA 1959	Texas, USA	5 years	Dryland winter wheat, sorghum, and tilled fallow	Wheat or sorghum planted as competitive crop	Competition	0.168
				Sweep cultivation 10 days after field bindweed emergence	Mechanical	-1.388
WILSON ET AL 1942	Minnesota, USA	4 years	Corn, hemp, millet, sorghum, soybeans,	Intensive cultivation followed by seeding with corn, hemp, millet,	Integrated	-5.221

*Citations in italics are studies that were conducted in both annual and perennial systems and are included in both Appendix 1 and 2.

Appendix 1: Studies used in systematic review and quantitative analysis of non-chemical field bindweed control in annual systems.

CITATION	STUDY LOCATION(S)	STUDY DURATION	CROPPING SYSTEM/PHASE	INTERVENTION UNDER INVESTIGATION	INTERVENTION CATEGORY	MEAN EFFECT SIZE
			sudangrass, or sunflowers	sorghum, soybeans, sudangrass, or sunflowers		
WOZNIAK 2012	Lublin, Poland	3 years	Pea	Plough tillage: skimming done after the harvest and autumn ploughing	Mechanical	-0.916
ZASADA ET AL 2003	California, USA	1 year	Ornamental plant production system	Solarization with clear tarp for 6 weeks	Solarization	-0.456

*Citations in italics are studies that were conducted in both annual and perennial systems and are included in both Appendix 1 and 2.

Appendix 2: Studies used in systematic review and quantitative analysis of non-chemical field bindweed control in perennial systems.

CITATION	STUDY LOCATION(S)	STUDY DURATION	CROPPING SYSTEM/PHASE	INTERVENTION UNDER INVESTIGATION	INTERVENTION CATEGORY	MEAN EFFECT SIZE
ABU-DIEYEH AND WATSON 2007	Quebec, Canada	2 years	Turf	*Sclerotina minor* fungus	Biocontrol	0.045
				Overseeding	Competition	0.023
				Pathogen and overseeding	Integrated	-1.428
BAKKE AND GAESSLER 1945	Iowa, USA	1 year	Not specified; "Hospital grounds"	Shading with cloths with varying degrees of light transmission	Shading	-3.776
BAKKE ET AL 1939*	Iowa, USA	2 years	Alfalfa stand	Alfalfa grown for 3 to 4 years	Competition	0.018
BAUMGARTNER ET AL 2010	California, USA	3 years	Vineyard	Cultivation followed by rye or tritcale cover crop	Crop Diversification	-0.517
BENIZRI AND AMIAUD 2005	Northeast France	1 year	Permanent grassland	Fertilizer at 120 kg N/ha/year	Soil Amendments	-0.704
BOSS ET AL 2007	Switzerland	2 years	Meadow	*Stagonospora convolvuli* fungus	Biocontrol	-1.107
BRANT ET AL 2004	Prague, Czech Republic	5 years	Pasture	3 cuts and remove for hay in grass sward	Mowing	1.335
			Pasture	2 cuts and leave for mulch in grass sward	Integrated	2.282
DERCHEID ET AL 1970	Presho, South Dakota	4 years	Alfalfa, intermediate wheatgrass, or crested wheatgrass stand	Culivation followed by sowing alfalfa, intermediate wheatgrass, or crested wheatgrass. Hayed for 4 years	Competition	0.438

*Citations in italics are studies that were conducted in both annual and perennial systems and are included in both Appendix 1 and 2.

Appendix 2: Studies used in systematic review and quantitative analysis of non-chemical field bindweed control in perennial systems.

CITATION	STUDY LOCATION(S)	STUDY DURATION	CROPPING SYSTEM/PHASE	INTERVENTION UNDER INVESTIGATION	INTERVENTION CATEGORY	MEAN EFFECT SIZE
DERCHEID 1978	Scotland, South Dakota	4 years	Perennial forage crops including alfalfa, smooth brome, intermediate wheatgrass	Various perennial forage crops tested for field bindweed suppression over 4 years	Competition	-2.133
GUNTLI ET AL 1998	Switzerland	1 year	Cemetary landscaping	*Stagonospora convolvuli* fungus	Biocontrol	-0.835
HASSAN ET AL 2006	Kalubia Governorate, Egypt	2 years	Orange orchard	Hand or mechanical hoeing two times	Mechanical	-0.609
			Orange orchard	Black polyethylene mulch	Mulch	-2.378
			Orange orchard	Rice straw mulch	Mulch	-1.868
HEINY 1994	Colorado, USA	2 years	Smooth brome stand	*Phoma proboscis* fungal biocontrol	Biocontrol	-0.078
KINCH AND KEIM 1937	Nebraska, USA	2 years	Turf	Hand pulling at regular intervals	Mechanical	-1.728
MENNAN ET AL 2006	Samsun, Turkey	2 years	Hazelnut orchard	Rotary hoeing	Mechanical	-0.478
				Cutting by sickle	Mowing	-0.357
NECHOLS 1995	Kansas, USA	Not stated	Not stated	Field bindweed moth *Tyta luctuosa*	Biocontrol	-1.109
ROSENTHAL AND HOSTETTLER 1980	Rome, Italy	1 year	Grassy field and cultivated area	*Galeruca rufa* beetle	Biocontrol	-0.595

*Citations in italics are studies that were conducted in both annual and perennial systems and are included in both Appendix 1 and 2.

Appendix 2: Studies used in systematic review and quantitative analysis of non-chemical field bindweed control in perennial systems.

CITATION	STUDY LOCATION(S)	STUDY DURATION	CROPPING SYSTEM/PHASE	INTERVENTION UNDER INVESTIGATION	INTERVENTION CATEGORY	MEAN EFFECT SIZE
			Alfalfa stand	Cultivated, seeded to alfalfa, and left in alfalfa for two years	Integrated	-4.148
STAHLER AND CARLSON 1947	Minnesota, USA	4 years	Pasture	Either alfalfa + bromegrass or alfalfa + reed canarygrass seeded and grazed	Grazing	-0.044
TAYLOR AND SMITH 2003	New Mexico, USA	2 years	Wetland	Periodic sustained flooding during growing season	Flooding	-1.099
				Shallow disking 30 days after wetland drawdown	Mechanical	-2.092
TIMMONS 1950	Kansas, USA	4 years	Pasture seeded to buffalograss, bentgrass, or bermudagrass	Various forage grasses sown, various watering regimes, and various mowing regimes	Integrated	-2.056
ULLOA ET AL 2010	Nebraska, USA	1 year	Pasture dominated by barnyard grass, field bindweed, etc	Flaming (87 kg propane/hectare) applied to field bindweed	Flaming	-2.82

*Citations in italics are studies that were conducted in both annual and perennial systems and are included in both Appendix 1 and 2.