Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

Cover Crop for Early-Season Weed Suppression in Crops: Systematic Review and Meta-Analysis

O. Adewale Osipitan[*1], J. Anita Dille[2], Yared Assefa[2], Stevan Z. Knezevic[1]

[1]Northeast Research and Extension Center, Haskell Agricultural Laboratory, University of Nebraska-Lincoln, Concord, NE 68728

[2]Kansas State University, Dept. of Agronomy, Throckmorton Hall, Manhattan, KS 66506

*Corresponding author: waleos@unl.edu

ABSTRACT

Cover crops are gaining importance as their use has numerous benefits including improved soil health, reduced soil erosion, and weed suppression. Weeds are most competitive with crops at early growth stages and a management strategy that ensures early season weed suppression in crops is crucial for crop growth, development, and yield. In this study, systematic and meta-analytic reviews of published studies from 1990 to January 2017 were conducted to provide evidence on whether using cover crops can provide satisfactory weed suppression at termination of cover crop and up to seven weeks after planting of main crop. The impact of cover crops as a weed control input on main crop yield was also evaluated. A total of 46 relevant field studies were evaluated. Main crops were planted one to three weeks after termination of the cover crops. Overall, our meta-analysis results indicated that cover crops provided early season weed suppression comparable to those provided by chemical and mechanical weed control methods in cropping systems. However, individual studies that supported similar conclusion were 40%. The use of cover crops for early season weed suppression had no effect on main crop grain yields but could increase vegetable crop yields when compared to no cover crop. Decisions about selecting cover crops species type (broadleaf or grass) or number (single or mixtures) were not as important as identifying cover crops with inherently competitive characteristics that suppress weeds, such as high biomass productivity and persistent residue.

Core Ideas:

- Cover crops can effectively suppress weeds after termination and up to early stage of crop growth.
- Use of cover crops for early season weed suppression did not affect grain crop yield, but improved yield of vegetable crops.
- Use of a single cover crop species provided early weed suppression similar to that of cover crop species mixtures.
- There were differences in cover crop and main crop management among studies that evaluated cover crop for weed suppression; hence, efforts should be made to understand how these approaches could influence the effectiveness of cover crop for weed suppression.

Abbreviations: CC, cover crop; NCC, no cover crop; MD, mean difference; WAP, weeks after planting or transplanting

Weeds occurring during early crop growth need to be removed as these are known to be most competitive with crops (Knezevic et al., 2002; Norsworthy and Oliviera, 2004; Tursun et al.,

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

2016; Osipitan et al., 2016). Uncontrolled weeds at this early growth stage could cause irreversible and substantial crop yield losses (Knezevic et al., 2002, Adigun et al., 2014). If weeds are controlled at this time, crops can get a head start, achieve canopy closure, and compete effectively with later emerging weeds (Rajcan and Swanton, 2001).

Typical early season weed control options include pre-plant, pre-emergence, and early post emergence herbicide applications in no-till cropping systems or mechanical cultivation in tilled systems. Herbicides provide an easy and cost-effective way of controlling weeds in crops and result in increased crop vigor and yield. Conversely, they are also a potential threat to the environment (e.g., pesticides residues in surface and/or groundwater) and in some areas, the development of resistant weed biotypes has reduced the utility of herbicides. In tillage-based cropping systems, mechanical operations such as plowing, harrowing, disking and cultivating are used. Tillage for weed control has been utilized for a long time (Abdin et al., 2000) as it reduces weed density. At the same time, weed seeds receive a brief exposure to sunlight, due to soil inversion after tillage that can trigger their germination. There are still concerns about the negative impact of tillage on soil health and topsoil erosion (Loaiza Puerta et al., 2018).

Cover crops have been documented to improve soil quality and minimize environmental degradation while providing a level of weed suppression in crops (Bachie and McGiffen, 2013; Norsworthy et al., 2007; Petrosino et al., 2015; Teasdale and Mohler, 2000). Cover crops can potentially provide an alternative tactic for control of herbicide-resistant weeds (Price et al., 2016; Wiggings et al. 2016). Reported weed suppression provided by cover crops has not been consistent, as it can range from 0% weed control (Galloway and Weston, 1996) to 98% control (Hayden et al., 2012), perhaps due to environmental, management or inherent factors (Teasdale, 1996). Cover crops provide weed suppression either through competition (Mirsky et al., 2013), smothering (Hutchinson and McGiffen, 2000), or allelopathic activity (Barnes et al., 1987; Kunz et al., 2016). Cover crops can either be inter-seeded (Abdin et al., 2000; Uchino et al., 2015) or sown in rotation with the main crop (Burgos and Talbert, 1996; Petrosino et al., 2015). For example, a cover crop inter-seeded three weeks after main crop emergence resulted in 59 and 75% weed biomass reduction in soybean (Uchino et al. 2015) and corn (Abdin et al., 2000), respectively. Cover crops reduced early season weed densities by 60 to 90% with no effect on crop yield when terminated one to two weeks before planting of main crops (Teasdale, 1993; De Haan et al., 2016).

Concerns over satisfactory weed control by cover crops alone have limited adoption of cover cropping as an alternative or component of an integrated weed management system (Price and Norsworthy, 2013). Other factors limiting cover crop adoption are additional management and increased costs, particularly, in seeding and termination (Vincent-Caboud et al. 2017; Zhou et al., 2017). Various studies have evaluated how cover crops could reduce weed density and biomass in some specific cropping systems. However, a robust review on whether cover crops can provide satisfactory early weed control comparable to conventional weed control methods such as tillage and herbicide across different crop production systems is needed.

Systematic reviews and meta-analyses are methods that have been widely used for quantitative research reviews (Miguez and Bollero, 2005; Kettenring and Adams, 2011; Basche et al., 2014; Egan et al., 2014; Shrestha et al., 2016). Systematic reviews ensure that a comprehensive survey of primary studies occurred, with a goal of reducing bias by appraising and synthesizing the surveyed studies based on a set of criteria to answer a review question (Uman, 2011; Ekong et al., 2015; Phan et al., 2015a). However, it should be noted that studies showing significant effect of treatments are more likely to be found in a survey of the literature than those studies showing

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

no effects, as the former are more often submitted and accepted for publication than the later (Higgins et al., 2003).

Data extracted through a systematic review are summarized into single quantitative estimates or effect sizes by a statistical technique known as meta-analysis (Haddaway et al., 2015). These review methods can be beneficial because they rely on quantitative information and allow for testing of hypotheses that cannot be satisfactorily answered by a single study (Phan et al., 2015a).

In this study, a systematic review and meta-analysis were conducted to evaluate the relative impact of using cover crops: (1) on weed biomass and density at termination of cover crop; (2) on weed biomass, density, and percentage weed control through 7 weeks after planting (WAP) of main crop (or after transplanting in vegetables); (3) as a weed management practice on main crop yield; and (4) on weed biomass, weed density, and main crop yield between cover crop types (broadleaf vs grass) and mixtures (any combination of two or more cover crop species).

MATERIALS AND METHODS

Literature Search

The primary literature search was carried out using the ISI Web of Science and Scopus databases using these terms: "(cover-crop OR rye OR vetch OR radish OR cowpea OR triticale) AND (weed OR weed-biomass OR weed-density OR weed-control) AND (crop OR legume OR cereal OR grain OR vegetable)". No language restriction was applied and years of publication were from 1990 to 2017. All searches were concluded on January 6, 2017. Hand search of authors' collections of relevant peer-reviewed articles were also included. All citations located in the searches were entered into ProQuest RefWorks (Cambridge Information Group, Bethesda, Maryland). Duplicate references (where information about study setting/location, title, and the study period were the same for different articles) were removed, and abstracts obtained for all remaining citations.

Criteria for including a paper:

(1) Research results reported weed biomass, density or percentage control following a cover crop (CC) and for another weed control option,

(2) The other weed control option (no cover crop, NCC) was specified and could be use of herbicide or tillage for weed control. All physical weed control methods were grouped as tillage including weeding by hand or hoeing,

(3) Time periods of evaluating weed control were indicated; specifically weed data collected at time of CC termination through to 7 WAP,

(4) Studies conducted in field settings and treatments were randomized with replications,

(5) Yield data for main crop following the use of cover crop for weed control might be reported; study was not excluded if no yield was reported,

(6) Sufficient information was provided to estimate standard deviation (SD) of mean values for weed biomass, weed density, weed control (%) and/or main crop yield as treatment effects of CC and NCC.

Full articles were obtained for all abstracts that met these research criteria, as well as those abstracts that indicated such data existed. In some cases, study authors were contacted for clarification. The experimental designs of these studies were either randomized complete blocks or split-plot designs with three to eight replications. Year and location were considered as the true replication within each study and then the standard deviation was estimated. The relevance

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

screening form, data extraction, and assessment of quality of reporting form were created in a spreadsheet (Microsoft Excel, Microsoft Corp., Redmond, WA, USA).

DATA ANALYSIS

All measurements from each study were standardized to common units. Weed biomass was reported in g m^{-2}, weed densities were in plants m^{-2}, and percentage weed control was in reference to non-treated weedy check. Main crop yield was reported in kg ha^{-1}. As an initial step, a meta-regression analysis was conducted to determine whether (1) use of herbicide and tillage, (2) crop production system (grain or vegetable crop), (3) location of study (Asia, Europe, North America, and South America), and precipitation had an influence on mean difference between CC and NCC.

In this meta-analysis, effect sizes were summarized with mean differences between the effect of CC and NCC on each weed response variable and on main crop yield. A random-effects model was used as it takes into account the diversity in factors that could influence primary treatment effects associated with study location, management practices, and cropping system. Weed suppression measures were classified into subgroups (weed biomass and weed density) while percentage weed control was analyzed separately in the meta-analysis. Cropping systems (main crops) were grouped into grain crops or vegetables in the meta-analysis. Higgins I^2 statistic was used to estimate the percentage of total variation in mean difference across the studies in each subgroup and overall, owing to heterogeneity rather than chance, with p-value < 0.05 considered as substantial heterogeneity. Mean difference within group was considered significant if the 95% confidence interval (CI) did not contain zero (null hypothesis). Overall mean difference was determined with Z-test and differences existed if p-value < 0.05.

Mean differences between CC and NCC on weed biomass, weed density, percentage weed control, and on main crop yield were presented with forest plots (Borenstein et al., 2009). The forest plot summarized the meta-analysis by showing if the overall or subgroup effect was based on many studies or a few, and to show whether studies varied substantially (Borenstein et al., 2009).

The differences between CC and NCC were evaluated for weed biomass and density at termination of cover crop and up to 7 WAP of main crop. The comparison to NCC at termination of CC was in reference to fallow or bare land (collectively called fallow), while comparison to NCC after planting of main crop was in reference to herbicide or tillage. The differential influence of type of CC (broadleaf and grass) or of single (one) versus mixed (more than one) CC species on weed biomass and density and on main crop yield were evaluated. Analyses were conducted with “meta” package in R version 3.4.1 (R Core Team, 2017).

RESULTS

From initial searches, 894 potentially relevant studies, all written in English, were identified (882 from databases and 12 from hand-search; Figure 1). After primary screening of titles and abstracts, 77 studies were selected for full-text screening. A total of 46 relevant studies satisfied inclusion criteria and provided enough information for estimation of standard deviation of the response variables. Of the 46 studies, 36 were conducted in North America, 6 in Europe, 3 in Asia, and 1 in South America. Studies from United States alone accounted for 72% of the total studies used for this review (Figure 2A). Of the total studies, 94% planted cover crops in the fall while 6% planted cover crops in the spring. These cover crops were terminated mechanically (70% of studies) or with herbicides (30% of studies). Herbicides used for terminating the cover

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

crop were either residual or non-residual, with non-residual accounting for 96% of cases. The performance of cover crop terminated with residual herbicides was only evaluated at termination to avoid confounding effect of these herbicides during the main crop growing season. Main crops were planted within one to three weeks after termination of cover crop. Tillage and herbicide as NCC treatments were reported in 70 and 30% of the studies, respectively (Figure 2B). Of the total studies, two reported inter-seeding cover crop with main crop.

Some level of weed control by using a cover crop was measured in 32 studies by weed biomass, 18 studies by weed density, and 4 studies by percentage weed control, while 25 studies reported main crop yields (Figure 3). Corn yield was reported in 21% of all studies and was the most reported main crop (Table 1). Hairy vetch (*Vicia villosa*) and cereal rye (*Secale cereale*) were the most reported broadleaf and grass cover crop species, respectively (Table 1). Some of the important broadleaf weeds studied were redroot pigweed (*Amaranthus retroflexus*), common lambsquarters (*Chenopodium album*), Palmer amaranth (*Amaranthus palmeri*), and velvetleaf (*Abutilon theophrasti*). Dominant grass weeds were green foxtail (*Setaria viridis*), large crabgrass (*Digitaria sanguinalis*), and bermudagrass (*Cynodon dactylon*) (Table 1).

An initial meta-regression analysis showed that comparing use of CC to herbicide or tillage separately had no differential influence on the effect size or mean difference for weed biomass, weed density, percentage weed control, and main crop yield (Table 2). Hence, herbicide and tillage treatments from the primary studies were grouped as NCC. The crop production system and location of study influenced the mean difference for main crop yield. Location of study influenced the effect sizes of weed biomass and density (Table 2). Annual precipitation of study locations ranged from 100 to 1600 mm. For example, studies on cover crop and weed suppression in corn and soybean were conducted in locations with annual precipitations > 750 mm (see Appendix B).

Weed suppression with cover crops

At termination of CC prior to planting of the main crop, there was an overall mean difference (MD) between CC and NCC on both weed biomass (MD = -42.94 g m^{-2}; 95% CI= -84.74 to -1.14; P<0.01) and weed density (MD = -6.15 plants m^{-2}; 95% CI= -9.42 to -2.89; P<0.01), with an overall beneficial impact on weed suppression (MD = -8.16; 95% CI = -15.93 to -0.38; P<0.01). Overall, there was significant heterogeneity (I^2 = 70%) among studies (Figure 4). Subgroup analysis showed significant heterogeneity (I^2 = 77%) among studies that measured weed biomass, but no significant heterogeneity among studies that measured weed density (Figure 4). For example, among studies that measured weed biomass, four out of the six studies showed no significant difference between CC and NCC.

The overall mean difference for weed biomass and density in the presence of CC during the early part of the growing season, up to 7 WAP of main crop, were reduced when compared to NCC (MD = -27.66; 95% CI= -37.33 to -18.00; P<0.01), with significant heterogeneity (I^2 = 99%) among studies (Figure 5). Specifically, weed biomass was reduced by CC compared to NCC (MD = -25.99 g m^{-2}; 95% CI= -38.56 to -13.42), with significant heterogeneity (I^2 = 99%) among studies, such that eight of the eleven studies were at variance with the summarized effect Weed density was reduced by CC more than NCC (MD = -35.09 plants m^{-2}; 95% CI= -53.44 to -16.74). There was significant heterogeneity (I^2 = 74%) among studies that reported weed density, with six out of the ten studies indicating no significant difference between CC and NCC. Cover crop had greater percentage weed control for 7 WAP of main crop compared to NCC (MD = 12.85%; 95% CI= -8.04 to 17.65; P<0.01), with no heterogeneity among studies (Figure 6).

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

Relative impact of cover crop as a weed control practice on main crop yield

Crop production systems were broadly grouped into grain and vegetable crops (Figure 7). Overall, there was no difference in main crop yield between CC as a weed control practice and NCC, with overall significant heterogeneity (I^2 = 70%) among studies but these differences were not maintained in subgroup (crop class) analysis (Figure 7). In grain (corn, cowpea, soybean, and wheat), there was no difference between CC and NCC on yields, while in vegetable crops (collard, cucumber, lettuce, pepper and tomato), greater main crop yields were obtained with CC compared to NCC (MD = 1478 kg ha^{-1}; 95% CI = 67 to 2888), with significant heterogeneity (I^2 = 81%) among studies (Figure 7).

Impact of type of cover crop and mixture on weed suppression and crop yield

A mixture of CC species reduced weed biomass (MD = -41.0 g m^{-2}; 95% CI = -50.14 to -31.86) and weed density (MD = -39.0 plants m^{-2}; 95% CI = -68.15 to -9.85) compared to NCC when measured up to 7 WAP (Figure 8). Similarly, the use of a single species of CC compared to NCC reduced weed biomass (MD = -36.0 g m^{-2}; 95% CI = -45.30 to -26.70) but not weed density (MD = -20.0 plants m^{-2}; 95% CI = -45.02 to 5.02) for the same period of observation. Broadleaf CC species reduced weed biomass (MD = -22.0 g m^{-2}; 95% CI = -34.25 to -9.75) but not weed density when compared to NCC up to 7 WAP. A grass CC species compared to NCC had no difference in weed biomass and density (Figure 8).

A mixture of CC species reduced yield for grain crops (MD = -1100 kg ha^{-1}) compared to NCC, but this reduction was not significant (95% CI = -5662 to 3462), whereas, vegetable crop yields were greater (MD = 5900 kg ha^{-1}; 95% CI = 3939 to 7861) with mixture of CC species (Figure 9). Sowing a single CC species compared to NCC resulted in greater main crop yields for vegetable crops, compared to NCC, but not for grain crops. Broadleaf or grass CC species compared to NCC produced greater vegetable crop yields (MD = 2900 kg ha^{-1}; 95% CI = 307 to 5493) but not grain crop yields (Figure 9).

Specific impacts of CC type (broadleaf vs grass) on corn (a grass crop) and soybean (a broadleaf crop) yields were evaluated (Figure 10). Analysis showed that there was no difference in CC type on corn and soybean yield compared to NCC

DISCUSSION

A weed management strategy that ensures early season weed suppression in crops would help make available the limited resources that are crucial for crop growth, development, and yield. This systematic review and meta-analysis demonstrated that (1) cover crops can provide weed suppression at termination and up to early stages of main crop growth, (2) use of cover crops for early weed suppression did not affect yields of grain crop, but improved yield of vegetable crops, (3) single or mixtures of cover crop species provided similar levels of early weed suppression , (4) grass and broadleaf cover crop species were both effective in providing early weed suppression, (5) a single or mixture of cover crop species compared to NCC had greater vegetable crop yields, and (6) use of broadleaf or grass cover crop species compared to NCC increased vegetable crop yields.

Weed suppression by using cover crops is gaining more attention in reduced and no tillage systems, in particular as an increasing number of weed species are evolving resistance to herbicides (Petrosino et al., 2015; Oliveira et al., 2017; Osipitan and Dille, 2017). Previous research has shown that early season weed suppression by using cover crops with conservation

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

tillage systems is comparable to chemical and mechanical control (Teasdale and Mohler, 1992; Johnson et. al. 1993). The degree of weed suppression provided by a cover crop depends on persistence of its residue, surface cover, and cover and main crop management strategies (Saini et al. 2006; Campiglia et al., 2014).

Reported mechanisms by which cover crops suppress weeds include modification of soil microclimate (Stigter, 1984), inhibition of light penetration through cover crop residues (Creamer et al., 1996), physically impeding weed seedling emergence through cover crop residues (Teasdale and Mohler, 2000), competition with weeds for resources by living cover crops (Hartwig and Ammon, 2002; Teasdale et al., 2007), and by selective allelopathic activity (Weston, 1996; Caamal-Maldonado, 2001).

As cover crops provide weed suppression, our analysis showed that they did not significantly affect main crop yield and in vegetable crops, yields were improved compared to no cover crop. There were reported cases in which cover crop residues or inter-seeded cover crops reduced main crop plant stands (4 to 13%; Teasdale, 1993; Saini et al., 2006; Uchino et al., 2015), however, the reduced stands did not adversely affect crop yields. Liebert et al. (2017) projected that soybean stands may decrease by 29,100 plants ha^{-1} for every 1 Mg ha^{-1} increase in cover crop biomass.

Use of cover crops for weed suppression in dry conditions could potentially reduce main crop growth and yield. Cover crops growing into May have resulted in soil water depletion especially when spring rainfall was below normal (Clark et al., 1995; Well et al., 2016). In addition, inadequately terminated cover crop will continue to deplete the limited soil water at the detriment of the main crop (Nielsen et al., 2016).

Cover crop residues persist long enough to provide weed suppression during the shorter growing season for transplanted vegetable crops (32 to 61 days) compared to the longer growing season for grain crops (75 to 130 days). Within this short growing season of vegetable crops after transplanting, cover crop residues still have adequate amount of biomass and surface cover to reduce weed biomass and density at the critical stages of weed competition (Teasdale, 1996; Ngouajio and Mennan, 2005; Campiglia et al., 2014; Korres and Norsworthy, 2015). As cover crops provide weed suppression, legume cover crop may supply nitrogen into the soil and this promote main crop growth and yield (Ngouajio and Mennan, 2005).

Early season weed suppression with cover crops did not depend on whether it was a mixture or a single cover crop species. This was similar to reports by Burst and Gerhards (2012), Halde et al. (2014), Smith et al. (2014), and Licht et al. (2016). An underlying principle for using cover crops to provide weed suppression is to maximize residue biomass and surface cover, and this is not necessarily guaranteed by cover crops in a mixture (Brennan and Smith, 2005; Hayden et al., 2012; Gaweda et al., 2014; Smith et al., 2014; Nielsen et al., 2015), while in some cases, a single species provided similar or more biomass compared to a mixture (Hayden et al., 2012; Gaweda et al., 2014; Mehring et al., 2016; Liebert et al., 2017). For example, a rye cover crop and its mixture with hairy vetch with at least 330 and 364 g m^{-2} aboveground biomass, respectively, equally provided weed biomass suppression ranging from 95 to 98% (Hayden et al., 2012).

Our analysis showed that a mixture of cover crop species for weed suppression improved vegetable crop yields but may potentially reduce grain yields. Reports have shown that enhanced residue biomass provided by a cover crop mixture may result in poor main crop establishment, reduced early crop growth and in some cases, a net loss in yield (Liebl et al. 1992; Nielsen et al.,

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

2016; Liebert et al., 2017). An intermediate cover crop residue biomass (e.g., 5100 kg ha^{-1} compared to 3400 and 6800 kg ha^{-1}) was proven to maximize crop yield (Wicks et al., 1994).

There was heterogeneity among studies for most measurements of weed suppression and main crop yield. For example, 60% of the primary studies were at variance with the summarized effect between cover crop and no cover crop on weed suppression. This was not unexpected in a meta-analysis study (Phan et al. 2015b). Some research studies were conducted with more replications within a year, over years, and across location with less variance than others (see Figure 4 and 5). Hence, a conclusion that comes from a less replicated study with high variance weigh less than a study with more replications and less variance.

In addition, heterogeneity was expected as these field studies were conducted across different agronomic and environmental conditions around the world. Our analysis confirmed that differences in location of study could be a source of heterogeneity. Studies within United States, which accounted for 72% of the literature used for this study, also showed substantial heterogeneity for most measurements when studies from other locations where excluded, suggesting that there may be other sources of heterogeneity. Annual precipitation associated with each study location did not influence the effect sizes, as suggested by the meta-regression analysis. Most of the studies were conducted at locations with annual precipitation > 750 mm, which appears to be adequate for crop growth. If locations had annual precipitation < 500 mm, studies were conducted using irrigation (Hutchinson and McGiffen, 2000; Ngouajio et al., 2003). The main sources of heterogeneity could be differences in cover crop management, such as species used (e.g. cereal rye vs radish), time of seeding, fertilization practices, method of termination, time between cover crop termination and main crop planting, among others. As a next step, a study by these authors will be evaluating how these management practices could influence effectiveness of using cover crops for weed management. To address differences among the primary studies, a random-effects model was used for the meta-analysis. This model recognized the variance among studies, and summarized the effect sizes as weighted means based on these differences. Generally, there are differences between the sample sizes of the CC and NCC, with CC in most cases having higher sample sizes. This was addressed by the meta-analysis, as the confidence interval of a mean difference took account not only of the total sample size, but also the sample size in each cover crop and no cover crop (Borenstein et al., 2007).

CONCLUSION

Our review showed that there were diverse approaches in studies that measured weed suppression by cover crops in crop production systems. A review of these studies showed various factors relating to cover crop and main crop management, as well as inherent characteristics of the cover crop that could influence effectiveness of cover crop for weed control. Efforts should be made to understand how these management practices could influence the use of cover crop in weed control. This review showed that cover crop could provide early weed control comparable to those provided by chemical and mechanical weed control methods in cropping systems. The presence of cover crop for early weed control could help to increase vegetable crop yield when compared to no cover crop. Decision to use cover crop as a mixture, single, grass or broadleaf is not as important as selecting cover crop based on their inherent characteristics that suppress weeds. Some of these characteristics based on literature review are high biomass productivity, and persistent residue.

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

REFERENCES

Abdin, O.A., X.M. Zhou, D. Cloutier, D.C. Coulman, M.A. Faris, and D.L. Smith. 2000. Cover crops and interrow tillage for weed control in short season maize (*Zea mays*). Eur. J. of Agron. 12:93-102. doi:10.1016/S1161-0301(99)00049-0

Adigun, J., O.A. Osipitan, S.T. Lagoke, R.O. Adeyemi, and S.O. Afolami. 2014. Growth and yield performance of cowpea (*Vigna unguiculata* (L.) Walp) as influenced by row-spacing and period of weed interference in south-west Nigeria. J. Agric. Sci. 6(4): 188-198.

Bachie, O., and M.E. McGiffen. 2013. Effects of summer cover cropping on weed population density and biomass in a subsequent broccoli crop. p. 31–36. *In* International Conference on Sustainable Environment and Agriculture. IPCBEE. 57:31:36.

Barberi, P., and M. Mazzoncini. 2001. Changes in weed community composition as influenced by cover crop and management system in continuous corn. Weed Sci. 49: 491–499. doi: 10.1614/0043-1745

Barnes, J.P., A.R. Putnam, B.A. Burke, and A.J. Aasen. 1987. Isolation and characterization of allelochemicals in rye herbage. Phytochemistry 26(5):1385-1390. doi:10.1016/S0031-9422(00)81818-X

Basche, A.D., F.E. Miguez, T.C. Kaspar, and M.J. Castellano. 2014. Do cover crops increase or decrease nitrous oxide emissions? A meta-analysis. J. Soil Water Conserv. 69(6):471-482. doi:10.2489/jswc.69.6.471

Błażewicz-Woźniak, M., E. Patkowska, M. Konopiński, and D. Wach. 2015. The effect of no-ploughing tillage using cover crops on primary weed infestation of carrot. Acta Sci. Pol.

Hortorum Cultus 14(2):27–40.

Borenstein, M., L.V. Hedges, J.P.T. Higgins, and H.R. Rothstein. 2009. References, in Introduction to Meta-Analysis, John Wiley & Sons, Ltd, Chichester, UK. doi: 10.1002/9780470743386.

Borenstein, M., L. Hedges, and H. Rothstein. 2007. Meta-Analysis Fixed effect vs random effects. Test: 162. Available at www.meta-analysis.com.

Brennan, E.B., and R.F. Smith. 2005. Winter cover crop growth and weed suppression on the central coast of California. Weed Technol. 19:1017–1024. doi: 10.1614/WT-04-246R1.1

Brust, J., and R. Gerhards. 2012. Lopsided oat (*Avena strigosa*) as a new summer annual cover crop for weed suppression in Central Europe. p. 257–264. *In* German Conference on Weed Biology and Weed Control.

Burgos, N.R., and R.E. Talbert. 1996. Weed control and sweet corn (*Zea mays var. rugosa*) response in a no-till system with cover crops. Weed Sci. 44:355–361.

Butler, D.M., G.E. Bates, and S.E. Eichler Inwood. 2016. Tillage System and Cover Crop Management Impacts on Soil Quality and Vegetable Crop Performance in Organically Managed Production in Tennessee. HortScience 51(8): 1038–1044.

Caamal-Maldonado, J.A., J.J. Jiménez-Osornio, A. Torres-Barragán, and A.L. Anaya. 2001. The use of allelopathic legume cover and mulch species for weed control in cropping systems. Agron. J. 93:27-36. doi:10.2134/agronj2001.93127x

Campiglia, E., F. Caporali, E. Radicetti, and R. Mancinelli. 2010. Hairy vetch (*Vicia villosa* Roth.) cover crop residue management for improving weed control and yield in no-tillage

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

tomato (*Lycopersicon esculentum* Mill.) production. Eur. J. Agron. 33(2):94-102. doi: 10.1016/j.eja.2010.04.001

Campiglia, E., E. Radicetti, and R. Mancinelli. 2012. Weed control strategies and yield response in a pepper crop (*Capsicum annuum L.*) mulched with hairy vetch (*Vicia villosa Roth.*) and oat (*Avena sativa L.*) residues. Crop Prot. 33: 65–73. doi:10.1016/j.cropro.2011.09.016

Campiglia, E., E. Radicetti, P. Brunetti, and R. Mancinelli. 2014. Do cover crop species and residue management play a leading role in pepper productivity? Sci. Hortic. (Amsterdam). 166: 97–104. doi:10.1016/j.scienta.2013.12.018

Carr, P.M., G.G. Gramig, and M.A. Liebig. 2013. Impacts of organic zero tillage systems on crops, weeds, and soil quality. Sustain. 5(7): 3172–3201. doi:10.3390/su5073172

Carrera, L.M., A.A. Abdul-Baki, and J.R. Teasdale. 2004. Cover crop management and weed suppression in no-tillage sweet corn production. HortScience 39(6): 1262–1266.

Clark, A.J., A.M. Decker, J.J. Meisinger, and M.S. McIntosh. 1997. Kill date of vetch, and a vetch-rye mixture: I. Cover crop and corn nitrogen. Agron. J. 89(3): 427–433. doi:10.2134/agronj1997.00021962008900030010x

Creamer, N.G., M.A. Bennett, B.R. Stinner, J. Cardina, and E.E. Regnier. 1996. Mechanisms of weed suppression in cover crop-based production systems. HortScience 31(3):410–413.

Curran, W.S., L.D. Hoffman, E.L. Werner, and E.L. Werner2. 1994. The influence of a hairy vetch (*vicia villosa*) cover crop on weed control and corn (*zea mays*) growth and yield. Weed Technol. 8(4): 777–784. doi:10.1017/S0890037X00028682

Cutti, L., F.P. Lamego, A. Cezar, M. De Aguiar, T.E. Kaspary, C. Alberto, and G. Rigon. 2016.

Winter cover crops on weed infestation and maize yield. Rev. Caatinga 29(4): 885–891.

Davis, A.S. 2010. Cover-Crop Roller–Crimper Contributes to Weed Management in No-Till Soybean. Weed Sci. 58: 300–309. doi: 10.1614/WS-D-09-00040.1

De Haan, R.L., D.L. Wyse, N.J. Ehlke, B.D. Maxwell, and D.H. Putnam. 2016. Simulation of spring-seeded smother plants for weed control in corn (*Zea mays*). Weed Sci 42:35–43. doi: 10.1017/S0043174500084125

Egan, J.F., K.M. Barlow, and D.A. Mortensen. 2014. A meta-analysis on the effects of 2,4-D and dicamba drift on soybean and cotton. Weed Sci. 62:193–206. doi:10.1614/WS-D-13-00025.1

Ekong, P.S., M.W. Sanderson, and N. Cernicchiaro. 2015. Prevalence and concentration of *Escherichia coli* O157 in different seasons and cattle types processed in North America: a systematic review and meta-analysis of published research. Prev. Vet. Med. 121(1): 74-85. doi:10.1016/j.prevetmed.2015.06.019

Galloway, B.A., L.A. Weston, and L.A. Weston. 1996. Influence of Cover Crop and Herbicide Treatment on Weed Control and Yield in No-Till Sweet Corn (*Zea mays L.*) and Pumpkin (*Cucurbita maxima Duch*). Weed Technol. 10(2): 341–346. doi:10.1017/S0890037X00040069

Gawęda, D., M. Wesołowski, and C.A. Kwiatkowski. 2014. Weed infestation of spring barley (*Hordeum vulgare* l.) depending on the cover crop and weed control method. ACTA Agrobot. 67:77–84. doi:10.5586/aa.2014.007

Haddaway, N.R., P. Woodcock, B. Macura, and A. Collins. 2015. Making literature reviews

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

more reliable through application of lessons from systematic reviews. Conserv. Biol. 29(6): 1596–1605. doi:10.1111/cobi.12541

Halde, C., R.H. Gulden, and M.H. Entz. 2014. Selecting cover crop mulches for organic rotational no-till systems in Manitoba, Canada. Agron. J. 106:1193-1204. doi:10.2134/agronj13.0402

Hartwig, N.L., and H.U. Ammon. 2002. Cover crops and living mulches. Weed Sci. 50:688–699. doi: 10.1614/0043-1745(2002)050[0688:AIACCA]2.0.CO;2

Hayden, Z.D., D.C. Brainard, B. Henshaw, and M. Ngouajio. 2012. Winter annual weed suppression in rye–vetch cover crop mixtures. Weed Technol. 26:818–825. doi: 10.1614/WT-D-12-00084.1

Higgins, J.P.T., S.G. Thompson, J.J. Deeks, and D.G. Altman. 2003. Measuring inconsistency in meta-analyses. BMJ Br. Med. J. 327(7414): 557–560. doi:10.1136/bmj.327.7414.557

Hutchinson, C.M., and M.E. McGiffen. 2000. Cowpea cover crop mulch for weed control in desert pepper production. HortScience 35(2):196–198.

Isik, D., E. Kaya, M. Ngouajio, and H. Mennan. 2009. Weed suppression in organic pepper (*Capsicum annuum L.*) with winter cover crops. Crop Prot. 28: 356–363. doi:10.1016/j.cropro.2008.12.002

Johnson, G.A., M.S. Defelice, and Z.R. Helsel. 1993. Cover crop management and weed control in corn (*Zea mays*). Weed Technol. 7:425–430. doi:10.1017/S08900037X00027834

Kettenring, K.M., and C.R. Adams. 2011. Lessons learned from invasive plant control experiments: A systematic review and meta-analysis. J. Appl. Ecol. 48(4): 970–979. doi:

10.1111/j.1365-2664.2011.01979.x

Knezevic, S.Z., S.P. Evans, E.E. Blankenship, R.C. Van Acker, J.L. Lindquist, S.P. Evans, and E.E. Blankenship. 2002. Critical period for weed control : the concept and data analysis. Weed Sci. 50:773–786. doi:10.1614/0043-1745(2002)050[0773:CPFWCT]2.0.CO;2

Korres, N.E., and J.K. Norsworthy. 2015. Influence of a rye cover crop on the critical period for weed control in cotton. Weed Sci. 63:346–352. doi:10.1614/WS-D-14-00075.1

Kunz, C., D.J. Sturm, M. Sökefeld, and R. Gerhards. 2016. Weed suppression and early sugar beet development under different cover crop mulches. Plant Prot. .Sci. 52: 1-7. doi: 10.17221/109/2016-PPS

Lassiter, B.R., D.L. Jordan, G.G. Wilkerson, B.B. Shew, and R.L. Brandenburg. 2005. Influence of cover crops on weed management in strip tillage peanut. Weed Technol. 25(4): 568–573. doi:10.1614/WT-D-11-00064.1.

Lawley, Y.E., R.R. Weil, and J.R. Teasdale. 2011. Forage radish cover crop suppresses winter annual weeds in fall and before corn planting. Agron. J. 103:137-44. doi:10.2134/agronj2010.0187

Lawson, A., C. Cogger, A. Bary, and A.M. Fortuna. 2015. Influence of seeding ratio, planting date, and termination date on rye-hairy vetch cover crop mixture performance under organic management. PLoS One. 10(6), p.e0129597

Licht, M., L. Juchems, J. Comito, M. Helmers, and S. Carlson. 2016. Demonstrating Cover Crop Mixtures on Iowa Farmland : Management , Soil Health , and Water Quality Benefits. Farm Progress Report. 1:82.

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

Liebert, J.A., A. DiTommaso, and M.R. Ryan. 2017. Rolled mixtures of barley and cereal rye for weed suppression in cover crop–based organic no-till planted soybean. Weed Sci. 65:426-439. doi:10.1017/wsc.2016.23

Loaiza Puerta, V., E.I. Pujol Pereira, R. Wittwer, M. van der Heijden, and J. Six. 2018. Improvement of soil structure through organic crop management, conservation tillage and grass-clover ley. Soil Tillage Res. 180(February): 1–9. doi:S0167198718300850.

Liebl, R.E.X., F.W. Simmons, L.M. Wax, and E.W. Stoller. 1992. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean. Weed Technol. 6: 838–846. doi:10.1017/S0890037X00036356

Masiunas, J.B., L.A. Weston, S.C. Weller, and S.C. Weller2. 1995. The Impact of Rye Cover Crops on Weed Populations in a Tomato Cropping System. Weed Sci. 43(2): 318–32.3. doi:10.1017/S0004317450008124 8

Mehring, G.H., J.E. Stenger, and H.M. Hatterman-Valenti. 2016. Weed control with cover crops in irrigated potatoes. Agronomy 6(3): 2–11. doi:10.3390/agronomy6010003

Mennan, H., M. Ngouajio, D. Isik, B. Kose, and E. Kaya. 2006. The effects of cover crop on weed control. Commun. Agric. Appl. Biol. Sci. 71(3): 709–714.

Miguez, F.E., and G.A. Bollero. 2005. Review of corn yield response under winter cover cropping systems using meta-analytic methods. Crop Sci. 45:2318–2329. doi:10.2135/cropsci2005.0014

Mirsky, S.B., M.R. Ryan, J.R. Teasdale, W.S. Curran, C.S. Reberg-Horton, J.T. Spargo, M.S. Wells, C.L. Keene, and J.W. Moyer. 2013. Overcoming weed management challenges in cover crop–based organic rotational no-till soybean production in the eastern United States. Weed Technol. 27:193–203. doi:10.1614/WT-D-12-00078.1

Mischler, R.A., W.S. Curran, S.W. Duiker, and J.A. Hyde. 2010. Use of a rolled-rye cover crop for weed suppression in no-till soybeans. Weed Sci. 24: 253–261. doi:10.1614/WT-D-09-00004.1

Moonen, A.C., and P.B. Rberi. 2004. Size and composition of the weed seedbank after 7 years of different cover-crop-maize management systems. Eur. Weed Res. Soc. Weed Res. 44: 163–177. doi:10.1111/j.1365-3180.2004.00388.x

Moore, M.J., T.J. Gillespie, C.J. Swanton, and C.J. Swanton. 1994. Effect of Cover Crop Mulches on Weed Emergence, Weed Biomass, and Soybean (*Glycine max*) Development. Weed Technol. 8(3): 512–518. Available at http://www.jstor.org/stable/3988021.

Ngouajio, M., M.E. McGiffen, and C.M. Hutchinson. 2003. Effect of cover crop and management system on weed populations in lettuce. Crop Prot. 22: 57–64. doi: 10.1016/S0261-2194(02)00111-4

Ngouajio, M., and H. Mennan. 2005. Weed populations and pickling cucumber (*Cucumis sativus*) yield under summer and winter cover crop systems. Crop Prot. 24: 521–526. doi: 10.1016/j.cropro.2004.10.004

Nielsen, D. C., D.J. Lyon, G.W. Hergert, R.K. Higgins, and J.D. Holman. 2015. Cover crop biomass production and water use in the Central Great Plains. Agron. J. 107(6), 2047-2058. doi:10.2134/agronj15.0186

Nielsen, D.C., D.J. Lyon, R.K. Higgins, G.W. Hergert, J.D. Holman, and M.F. Vigil. 2016.

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

Cover crop effect on subsequent wheat yield in the central great plains. Agron. J. 108: 243–256. doi:10.2134/agronj2015.0372

Nord, E.A., M.R. Ryan, W.S. Curran, D.A. Mortensen, and S.B. Mirsky. 2012. Effects of management type and timing on weed suppression in soybean no-till planted into rolled-crimped cereal rye. Weed Sci. 60(4): 624–633. doi:10.1614/WS-D-12-00024.1

Norsworthy, J.K., and M.J. Oliveira. 2004. Comparison of the critical period for weed control in wide- and narrow-row corn. Weed Sci. 52(5):802-807. doi:10.1614/WS-03-165R:

Norsworthy, J.K., M.S. Malik, P. Jha, and M.B. Riley. 2007. Suppression of *Digitaria sanguinalis* and *Amaranthus palmeri* using autumn-sown glucosinolate-producing cover crops in organically grown bell pepper. Weed Res. 47:425–432. doi:10.1111/j.1365-3180.2007.00586.x

Oliveira, M.C., T.A. Gaines, F.E. Dayan, E.L. Patterson, A.J. Jhala, and S.Z. Knezevic. 2017. Reversing resistance to tembotrione in an *Amaranthus tuberculatus* (*var. rudis*) population from Nebraska, USA with cytochrome P450 inhibitors. Pest. Manag. Sci. doi:10.1002/ps.4697.

Osipitan, O.A., J.A. Adigun, and R.O. Kolawole. 2016. Row spacing determines critical period of weed control in crop: Cowpea (*Vigna unguiculata*) as a case study. Azarian J. Agric. 3(5): 90–96.

Osipitan, O.A. and J.A. Dille. 2017. Fitness Outcomes Related to Glyphosate Resistance in Kochia (*Kochia scoparia*): What Life History Stage to Examine? Front. Plant Sci. 7: 1–13. doi:10.3389/fpls.2017.01090

Petrosino, J.S., J.A. Dille, J.D. Holman, and K.L. Roozeboom. 2015. Kochia suppression with cover crops in southwestern Kansas. Crop Forage Turfgrass Manag 1. doi:10.2134/ cftm2014.0078

Phan, K., D.H. Tian, C. Cao, D. Black, and T.D. Yan. 2015. Systematic review and meta-analysis: techniques and a guide for the academic surgeon. Ann. Cardiothorac. Surg. 4(2): 112–22. doi:10.3978/j.issn.2225-319X.2015.02.04

Phan, K., P.J. Rao, A.C. Kam, and R.J. Mobbs. 2015. Minimally invasive versus open transforaminal lumbar interbody fusion for treatment of degenerative lumbar disease: systematic review and meta-analysis. *European Spine Journal*, *24*(5), 1017-1030.

Price, A.J., and J.K. Norsworthy. 2013. Cover crops for weed management in southern reduced-tillage vegetable cropping systems. Weed Technol. 27:212–217. doi:10.1614/WT-D-12-00056.1

R Core Team. (2017). *R: A Language and Environment for Statistical Computing*, Vienna: R Foundation for Statistical Computing.

Rajcan, I., and C.J. Swanton. 2001. Understanding maize-weed competition: Resource competition, light quality and the whole plant. Field Crop. Res. 71:139–150. doi:10.1016/S0378-4290(01)00159-9

Reddy, K.N., and C.H. Koger. 2004. Live and killed hairy vetch cover crop effects on weeds and yield in glyphosate-resistant corn. Weed Technol. 18:835–840. doi:10.1614/WT-03-228R

Sadeghpour, A., M. Hashemi, M. DaCosta, L.E. Gorlitsky, E. Jahanzad, and S.J. Herbert. 2014. Assessing winter cereals as cover crops for weed control in reduced-tillage switchgrass

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

establishment. Ind. Crops Prod. 62: 522–525. doi:10.1016/j.indcrop.2014.09.027

Saini, M., A. Price, and E. van Santen. 2006. Cover crop residue effects on early-season weed establishment in a conservation-tillage corn-cotton rotation. South. Conserv. Syst. Conf. Amarillo, TX. (July 2002): 175–182.

Samarajeewa, K.B.D.P., S., T. Horiuchi, and S. Oba. 2005. Effect of chinese milk vetch (*astragalus sinicus l.*) as a cover crop on weed control, growth and yield of wheat under different tillage systems. Plant Prod. Sci. 8(1): 79–85. doi:10.1626/pps.8.79

Singh, M.,M.S. Bhullar, and B.S. Chauhan. 2015. Influence of tillage, cover cropping, and herbicides on weeds and productivity of dry direct-seeded rice. Soil Tillage Res. 147: 39-49. doi:10.1016/j.still.2014.11.007

Shrestha, U., R.M. Augé, and D.M. Butler. 2016. A meta-analysis of the impact of anaerobic soil disinfestation on pest suppression and yield of horticultural crops. Front. Plant Sci. 7: 1–20. doi:10.3389/fpls.2016.01254

Smith, R.G., L.W. Atwood, and N.D. Warren. 2014. Increased productivity of a cover crop mixture is not associated with enhanced agroecosystem services. PLoS One 9(5):1–8. doi:10.1371/journal.pone.0097351

Smith, R.G., L.W. Atwood, F.W. Pollnac, and N.D. Warren. 2015. Cover-crop species as distinct biotic filters in weed community assembly. Weed Sci. 63:282-295. doi:10.1614/WS-D-14-00071.1

Stigter, C.J. 1984. Traditional use of shade: A method of microclimate manipulation. Arch. Meteorol. Geophys. Bioclimatol. Ser. B 34(1–2): 203–210.

Teasdale, J.R., C.E. Beste, and W.E. Potts. 1991. Response of weeds to tillage and cover crop residue. Weed Sci. 39:195-199. doi:10.1017/S0043174500071460

Teasdale, J.R. 1993. Reduced-herbicide weed management systems for no-tillage corn (*Zea mays*) in a hairy vetch (*Vicia villosa*) cover crop. Weed Technol. 7:879–883. doi:10.1017/S0890037X00037921

Teasdale, J.R. 1996. Contribution of cover crops to weed management in sustainable agricultural systems. J. Prod. Agric. 9(4): 475–479. doi:10.2134/jpa1996.0475

Teasdale, J.R., and C.L. Mohler. 1992. Weed suppression by resdue from hairy vetch and rye cover crops. Proceedings of the First International Weed Congress 2:516-528.

Teasdale, J.R., L. Brandsaeter, A. Calegari, and F. Neto. 2007. Cover crops and weed management. Non chemical weed management principles. Concepts and Technology, CABI, Wallingford, UK. 1:49-64.

Teasdale, J.R., and C.L. Mohler. 2000. The quantitative relationship between weed emergence and the physical properties of mulches. Weed Sci. 48: 385–392. doi:10.1614/0043-1745(2000)048[0385:TQRBWE]2.0.CO;2

Tursun, N., A. Datta, S. Budak, Z. Kantarci, and S.Z. Knezevic. 2016. Row spacing impacts the critical period for weed control in cotton (*Gossypium hirsutum*). Phytoparasitica 44(1): 139–149. doi:10.1007/s12600-015-0494-x.

Uchino, H., K. Iwama, Jitsuyama, Y. Jitsuyama, T. Yudate, S. Nakamura. 2009. Yield losses of soybean and maize by competition with interseeded cover crops and weeds in organic-based cropping systems. Field Crops Res. 113:342-351. doi:10.1016/j.fcr.2009.06.013

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

Uchino, H., K. Iwama, Y. Jitsuyama, T. Yudate, S. Nakamura, J. Gopal, and K. Iwama. 2015. Interseeding a cover crop as a weed management tool is more compatible with soybean than with maize in organic farming systems. Plant Prod. Sci 18(182): 187–196. doi:10.1626/pps.18.187

Uman, L.S. 2011. Systematic reviews and meta-analyses. J. Can. Acad. Child Adolesc. Psychiatry 20(1): 57–59.

Vincent-Caboud, L., J. Peigné, M. Casagrande, and E. Silva. 2017. Overview of organic cover crop-based no-tillage technique in Europe: farmers' practices and research challenges. Agriculture 7(5): 42. doi:10.3390/agriculture7050042

Wayman, S., C. Cogger, C. Benedict, I. Burke, D. Collins, and A. Bary. 2014. The influence of cover crop variety, termination timing and termination method on mulch, weed cover and soil nitrate in reduced - tillage organic systems. Renew. Agric. Food Syst. 30(5): 450-460. doi:10.1017/S1742170514000246

Wells, M.S., C.M. Brinton, and S.C. Reberg-Horton. 2016. Weed suppression and soybean yield in a no-till cover-crop mulched system as influenced by six rye cultivars. Renew. Agric. Food Syst. 31(5): 429-440. doi:10.1017/S1742170515000344

Weston, L.A. 1996. Utilization of allelopathy for weed management in agroecosystems. Agron. J. 88(6):860-6. doi:10.2134/agronj1996.00021962003600060004x

Wicks, G.A., D.A. Crutchfield, and O.C. Burnside. 1994. Influence of wheat (*Triticum aestivum*) straw mulch and metolachlor on corn (*Zea mays*) growth and yield. Weed Sci. 42:141–147. doi:10.1017/S0043174500084307

Wiggins, M.S., R.M. Hayes, and L.E. Steckel. 2016. Evaluating Cover Crops and Herbicides for Glyphosate-Resistant Palmer Amaranth (Amaranthus palmeri) Control in Cotton. Weed Technol. 30(2): 415–422. doi:10.1614/WT-D-15-00113.1

Zhou, X.V., J.A. Larson, C.N. Boyer, R.K. Roberts, and D.D. Tyler. 2017. Tillage and cover crop impacts on economics of cotton production in Tennessee. Agron. J. 109(5): 2087–2096. doi:10.2134/agronj2016.12.0733

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

Figure 1. Selection of studies for inclusion in the meta-analysis.

Figure 2: Location of study and weed control methods reported in the articles used for the meta-analysis.

Figure 3. The outcome measurements used in the meta-analysis. **A**: weed biomass at termination of cover crop, **B**: weed biomass up to 7 weeks after planting (WAP) of main crop, **C**: weed density at termination of cover crop, **D**: weed density up to 7 WAP of main crop, **E**: percentage weed control up to 7 WAP, **F**: main crop yield.

Figure 4. Forest plot comparing cover crop (CC) and no cover crop (NCC) in terms of weed biomass and weed density at termination of cover crop using random effect model.

Figure 5. Forest plot comparing cover crop (CC) and no cover crop (NCC) in terms of weed biomass and weed density up to 7 weeks after planting of main crop using random-effects model.

Figure 6. Forest plot comparing cover crop (CC) and no cover crop (NCC) in terms of percentage weed control up to 7 weeks after planting of main crop using random-effects model.

Figure 7. Forest plot comparing cover crop (CC) as a weed control input and no cover crop (NCC) in terms of crop production system using random-effects model.

Figure 8. Forest plot showing the differential influence of cover crop type (broadleaf, grass) and mixture (any combination of cover crop species) on weed biomass and weed density using random-effects model.

Figure 9. Forest plot showing the differential influence of cover crop type (broadleaf, grass) and mixture (any combination of cover crop species) used for weed control on main crop yield using random-effects model.

Figure 10. Forest plot showing the differential influence of cover crop type (broadleaf, grass) and mixture (any combination of cover crop species) used for weed control on corn and soybean yield using random-effects model.

Table1. Type of cover crop (top 20), weed species (top 20), and main crops in the studies used for the meta-analysis.

Cover crop	Number of studies (%)	Weed species	Number of studies (%)	Main crop	Number of studies (%)
Broadleaf:		**Broadleaf:**		**Grain:**	
Vicia villosa	13 (25)	*Amaranthus retroflexus*	16 (33)	*Zea mays* (corn)	11 (21)
Trifolium incarnatum	8 (15)	*Chenopodium album*	8 (15)	*Glycine max* (soybean)	5 (10)
Raphanus sativus	8 (15)	*Amaranthus palmeri*	7 (14)	*Oryza sativa* (rice)	1 (2)
Sinapis alba	6 (12)	*Abutilon theophrasti*	7 (14)	*Triticum aestivum* (wheat)	1 (2)
Vicia sativa	6 (12)	*Amaranthus tubaculatus*	6 (12)	*Vigna unguiculata* (cowpea)	1 (2)
Sinapis hirta	6 (12)	*Portulaca oleracea*	6 (12)		
Trifolium subterraneum	5 (10)	*Lamium amplexicaule*	6 (12)	**Vegetable:**	
Medicago sativa	2 (4)	*Conyza canadensis*	6 (12)	*Lactuca sativa* (lettuce)	2 (4)
		Solanum nigrum	6 (12)	*Capsicum annuum* (pepper)	2 (4)
		Solanum ptycanthum	5 (10)	*Lycopersicon esculentum* (tomato)	2 (4)
Grass:					
Secale cereal	14 (27)	*Polygonum aviculare*	4 (8)	*Brasica olerecea* (collard)	1 (2)
Avena sativa	9 (17)	*Rumex crispus*	4 (8)		
Lolium multiflorum	6 (12)	*Ipomoea purpurea*	4 (8)	*Cucumis sativus* (cucumber)	1 (2)
x Triticosecale	6 (12)	*convolvulus arvensis*	4 (8)		
Triticum aestivum	5 (10)				
Hordeum vulgare	3 (6)	**Grass and Sedges:**			
		Setaria viridis	9 (17)		
		Digitaria sanguinalis	7 (14)		
		Cynodon dactylon	7 (14)		
		Cyperus esculentus	6 (12)		
		Lolium perenne	6 (12)		
		Echinochloa crus-galli	6 (12)		

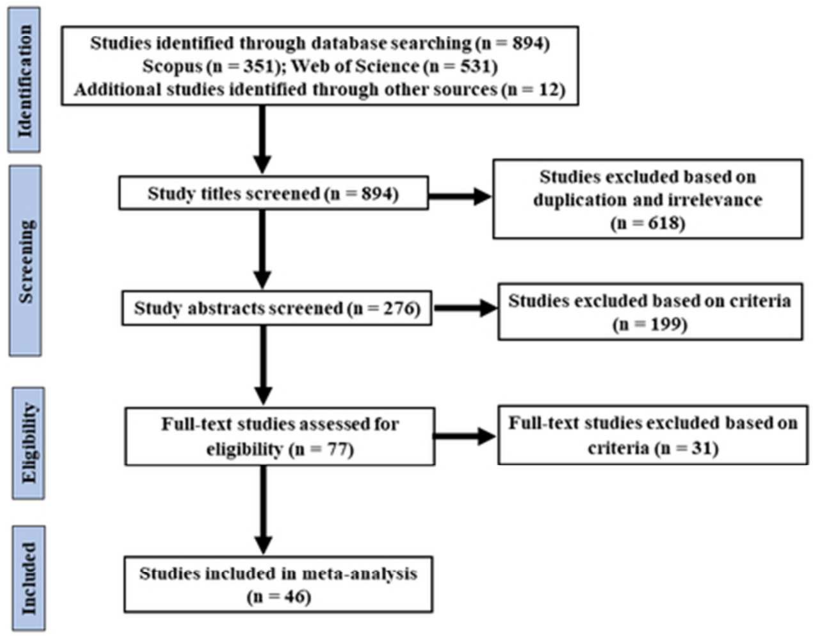
Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

672 Table 2. Meta-regression coefficients (*b*) and *P*-values indicating the influence of no cover crop (NCC) method, crop production
673 system, and region of study on mean difference between cover crop (CC) and NCC on weed measures from termination to 7 weeks
674 after planting main crop, and main crop yield. *b* is significant if $p < 0.01$ indicates.

Moderators	**DF**	**Weed biomass**		**Weed density**		**% Weed control**		**Main crop yield**	
		b	***P*-value**	***b***	***P*-value**	***b***	***P*-value**	***b***	***P*-value**
NCC method (Herbicide vs Tillage)	1	800	0.176	803	0.901	908	0.624	631	0.389
Crop production system (Grain vs Vegetable)	1	651	0.201	719	0.420	843	0.113	3210	0.004
Region of study (USA vs others)	1	701	0.024	651	0.037	912	0.273	2041	0.001
Precipitation (≤500 mm vs > 500 mm)	1	967	0.511	239	0.071	-	-	2453	0.098

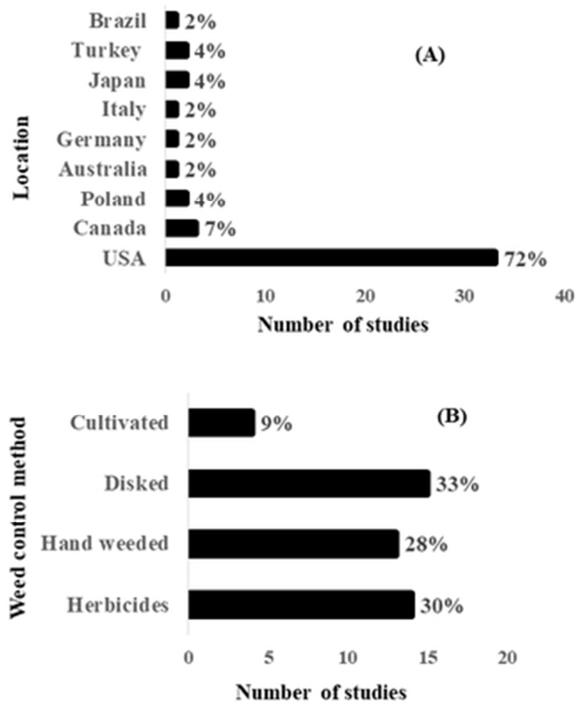
675 -: not estimated

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

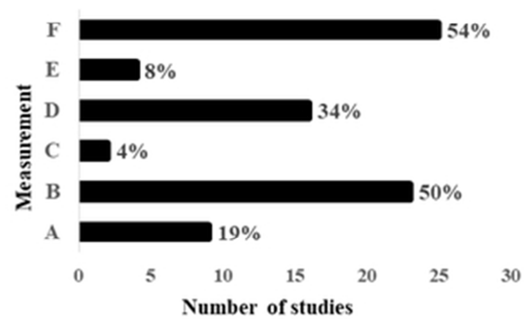


50x38mm (300 x 300 DPI)

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

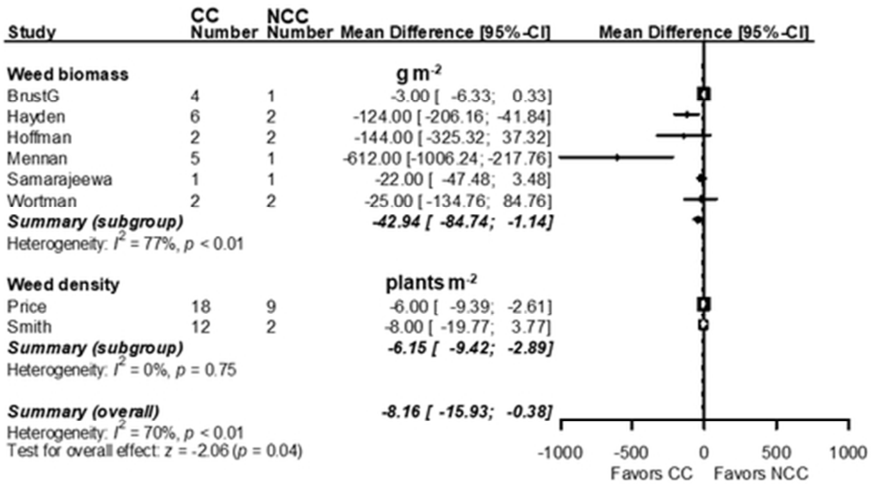


50x38mm (300 x 300 DPI)

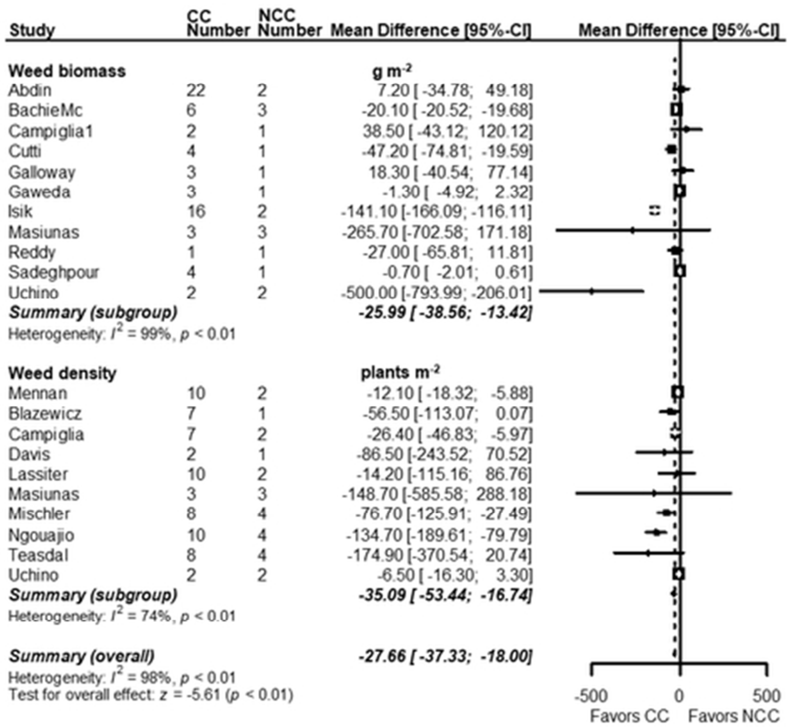


50x38mm (300 x 300 DPI)

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

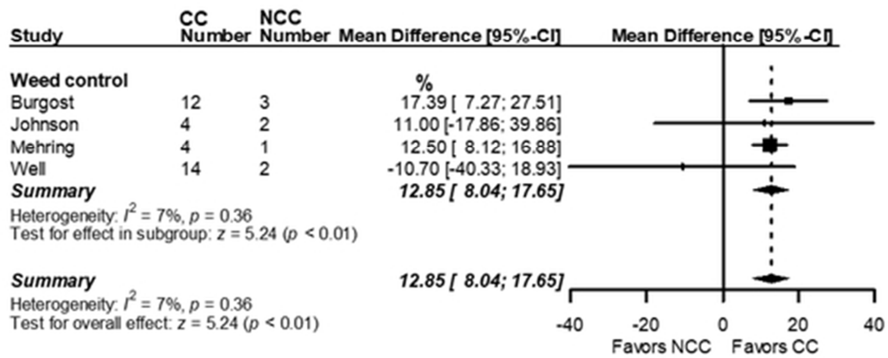


50x38mm (300 x 300 DPI)



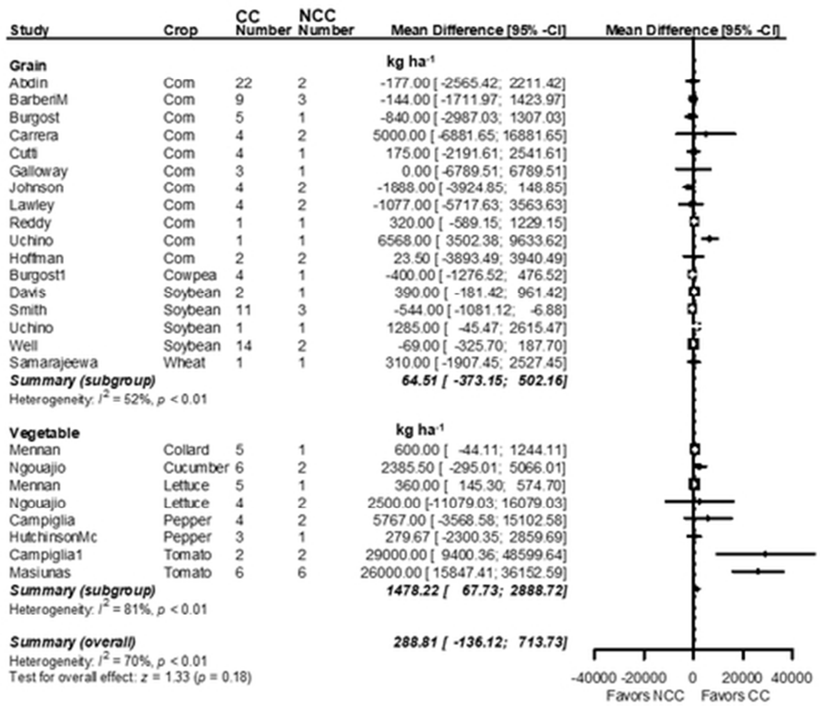
50x38mm (300 x 300 DPI)

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752



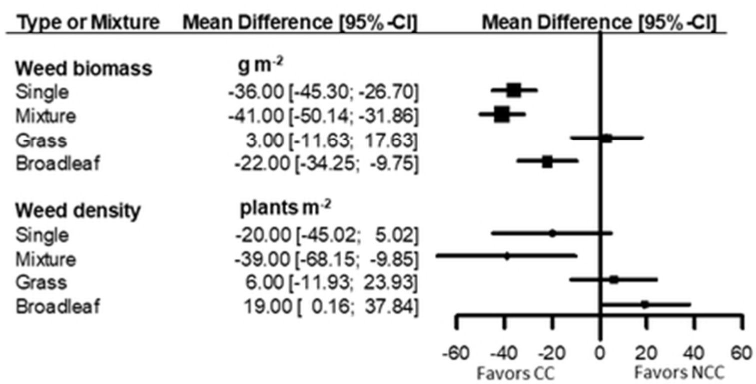
50x38mm (300 x 300 DPI)

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

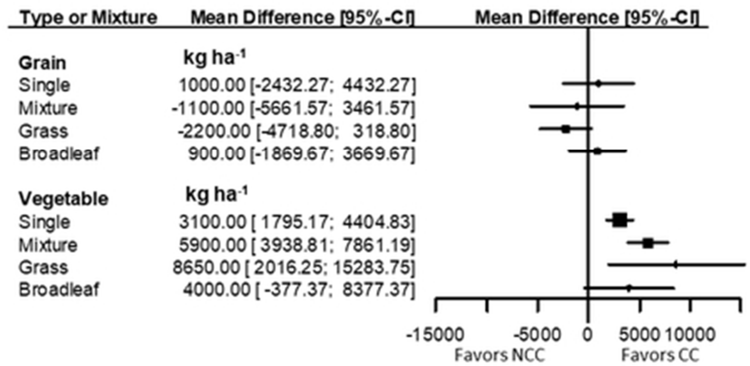


50x38mm (300 x 300 DPI)

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

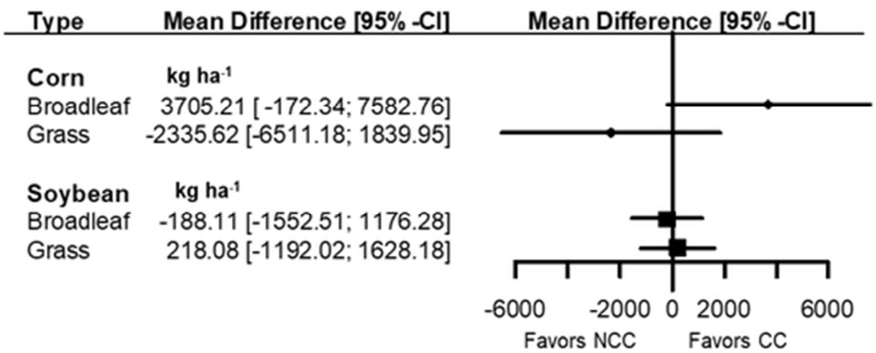


50x38mm (300 x 300 DPI)



50x38mm (300 x 300 DPI)

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752



50x38mm (300 x 300 DPI)

Appendix A: Articles used for the systematic review and meta-analysis.

Authors	Measurements			
	weed biomass	weed density	% weed control	crop yield
Abdin et al., 2000	X			corn
Bachie and McGiffen, 2013	X			
Barberi and Mazzoncini, 2001	X	X		corn
Blazewicz-Wozniak et al., 2015		X		
Brainard et al., 2008	X			
Brennan and Smith, 2005		X		
Brust and Gerhard, 2012	X			
Burgos and Talbert, 1996			X	corn
Butler et al., 2016		X		
Campiglia et al., 2010	X	X		tomato
Campiglia et al., 2012	X			pepper
Campiglia et al., 2014	X			corn
Carrera et al., 2004	X			corn
Hutchinson and McGiffen, 2000	X			pepper
Curran et al., 1994	X	X		corn
Cutti et al., 2016	X	X		corn
Davis, 2010	X	X		soybean
Galloway and Weston, 1996	X			corn
Gawęda et al., 2014	X			
Halde et al., 2014	X			
Hayden et al., 2012		X		
Hoffman et al., 1993	X			corn
Isik et al., 2009	X			
Johnson et al., 1993			X	corn
Reddy and Koger, 2004	X			
Lassiter et al., 2005		X		

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

Lawley et al., 2011	X			
Lawson et al., 2015			X	
Masiunas et al., 1995	X	X		tomato
Mehring et al., 2016			X	
Mennan et al., 2006	X			lettuce
Mirsky et al., 2013	X			
Mischler et al., 2010		X		
Ngouajio and Mennan, 2005		X		lettuce
Ngouajio et al., 2003	X			cucumber
Nord et al., 2012	X			
Price et al., 2016		X		cotton
Sadeghpour et al., 2014	X			
Samarajeewa et al., 2005	X			wheat
Smith et al., 2014	X			
Smith et al., 2015		X		soybean
Teasdale et al., 1991	X	X	X	
Uchino et al., 2009	X	X		corn, soybean
Uchino et al., 2015	X	X		corn, soybean
Well et al., 2016			X	soybean
Wortman et al., 2013	X			

Appendix B: Location of study and annual precipitation (at the year of study) for corn and soybean

Authors	Crop	Study location	Precipitation (mm)
Abdin et al. 2000	Corn	Quebec, Canada	755
Barberi and Mazzoncini, 2001	Corn	Central Italy	901
Burgost and Talbert, 1996	Corn	Fayetteville, AR	1000
Carrera et al., 2004	Corn	Beltsville, MD	1000
Cutti et al., 2016	Corn	RS, Brazil	800
Galloway and Weston, 1996	Corn	Lexington, KY	1050
Hoffman et al., 1993	Corn	Columbus, OH	1450
Johnson et al., 1993	Corn	Columbia, MO	1000
Lawley et al., 2011	Corn	Beltsville, MD	950
Reddy and Koger, 2004	Corn	Stoneville, MS	1400
Uchino et al., 2015	Corn	Saporo, Japan	1100
Davis, 2010	Soybean	Urbana, IL	975
Smith et al., 2014	Soybean	Madbury, NH	950
Uchino et al., 2015	Soybean	Saporo, Japan	1100
Well et al., 2016	Soybean	Salisbury, NC	980
Mennan et al., 2006	Collard	Samsun, Turkey	660
Ngouajio et al., 2003	Cucumber	Thermal, CA	100
Mennan et al., 2006	Lettuce	Samsun, Turkey	660
Ngouajio and Mennan, 2005	Lettuce	Lasing, MI	770
Campigilia et al., 2012	Pepper	Viterbo, Italy	755
Hutchinson and McGiffen, 2000	Pepper	Thermal, CA	100

Agron. J. Accepted Paper, posted 06/28/2018. doi:10.2134/agronj2017.12.0752

Campigilia et al., 2010	Tomato	Viterbo, Italy	754
Masiunas et al., 1995	Tomato	Champaign, IL	950