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Role of Winter Annual Weeds as Alternative Hosts for Soybean Cyst Nematode

William G. Johnson, Associate Professor of Weed Science, Purdue University, West Lafayette, IN 47907; **J. Earl Creech,** Extension Weed Specialist, University of Nevada Cooperative Extension, University of Nevada-Reno, Fallon, NV 89406; and **Valerie A. Mock,** Graduate Research Assistant, Purdue University, West Lafayette, IN 47907

Corresponding author: William G. Johnson. wgj@purdue.edu

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Abstract
Soybean cyst nematode (*Heterodera glycines* Ichinohe, SCN) has been reported to parasitize a broad range of host plants, encompassing nearly 150 legume and non-legume genera representing 22 plant families. Several SCN host species are common winter annual weeds in US soybean production fields and include purple deadnettle (*Lamium purpureum* L.), henbit (*Lamium amplexicaule* L.), field pennycress (*Thlaspi arvense* L.), shepherd's purse [*Capsella bursa-pastoris* (L.) Medik], common chickweed [*Stellaria media* (L.) Vill.], and smallflowered bittercress (*Cardamine parviflora* L.). The influence of winter annual weed management on SCN population densities has received little attention to date and warrants further investigation by multidisciplinary research involving weed scientists, nematologists, and soybean production specialists.

Introduction
Winter annual weed populations in production fields (Fig. 1) have been increasing due to the widespread adoption of conservation tillage practices and reduced reliance on herbicides with soil residual activity (37). A number of common winter annual weed species have recently been identified as alternative hosts for soybean cyst nematode (52). SCN has long been known as a threat to profitable soybean production throughout soybean growing regions of the United States. Current management systems for SCN include rotation to a non-host crop and use of SCN resistant soybean varieties but fail to address winter annual weed management. Failure to manage winter annual weeds may provide a niche for SCN reproduction and increase population density in the absence of soybean. The purpose of this review article is to summarize the current literature about the management implications of SCN and winter annual weed management.

Fig. 1. Winter annual weeds have become more common in crop fields due to reduced reliance on tillage and soil-applied herbicides.

Conservation tillage acreage in the United States has increased steadily from an estimated 70 million acres in 1990 to over 110 million acres in 2004 (5). Reduced soil disturbance associated with these systems has created a favorable environment for winter annual weed establishment and seed production (55). The widespread adoption of glyphosate-resistant (GR) crops is another trend that may have contributed to this recent abundance of winter weeds. In 2007, GR soybean was planted on approximately 91% of the soybean production hectares in the United States (3). Because glyphosate can be applied to emerged GR soybean, many growers delay herbicide applications until after crop planting which allows the winter annuals to mature and produce seed. In addition, increased use of glyphosate postemergence in soybean has led to decreased reliance on soil-residual herbicides. Pendimethalin, imazethapyr, and imazaquin were each applied on 21 to 45% of the United States soybean acres in 1996 but only 6 to 8% of the acreage in 2006 (4). These soil-residual herbicides can suppress fall emergence of winter annual weeds when applied in the spring (7). An additional factor that may have increased the prevalence of winter annual weeds has been the relatively mild winters experienced in recent years which have enhanced the ability of winter weed seedlings to avoid winter-kill (29).

Winter annual weeds can have a number of negative impacts on cropping systems. Dense populations of winter annual weeds can slow drying and warming of soil in the spring (8,19); the combination of which may lead to delayed planting dates and decreased yields (25). In conventionally-tilled fields, the presence of winter annuals can increase tillage, labor, and fuel costs required for spring seedbed preparation (8,19). These weeds can be difficult to control in no-till production systems with late spring herbicide applications because of their advanced growth stage. Similarly, winter annual weeds can interfere with crop seeding depth and crop establishment in high residue areas (29). Winter annual weeds can also host various crop pests. For example, common chickweed is a host for black cutworm (45), a common insect pest of corn.

Winter annual weeds can be managed with herbicides, tillage, and/or cover crops. Although the presence of winter annuals in production fields can be problematic, operations required to remove these plants may also have negative impacts on crop production systems. Tillage can be effective for control of winter annual weeds but it has also been linked to increased risk of soil erosion and can stimulate SCN population growth (27,61). Removal of winter annual weeds with a fall applied herbicide application results in bare soil that may warm and dry faster in the spring (31). However, these conditions have been observed to promote earlier emergence and subsequent management problems of summer annual weeds, giant foxtail, giant ragweed, common lambsquarters, and common waterhemp [(62), W. G. Johnson, *unpublished data*]. Finally, winter cover crops have been implicated in causing yield reductions in subsequent crops (20,21,51,54). Although not actively competing with the crop, terminated cover crops can reduce N availability (21,51,54), release allelopathic compounds (26,38), and limit moisture availability (10,11,33) — all of which can inhibit the growth and yield of the subsequent crop.

Soybean Cyst Nematode

SCN consistently ranks as the most economically important soybean pathogen in the United States (57,58). Since it was first detected in 1954 in North Carolina, SCN has been discovered in most US soybean production states and is especially common in Indiana where it currently infests at least 82 of 92 counties (22). Soybean yield losses within fields infested with SCN can range from 5% to 95% depending upon severity of infestation, soil type, soybean variety, weather conditions, and presence of other soybean pests (e.g., weeds, insects, and fungal pathogens) (43,44).

The life cycle of SCN begins inside the mature female with the fertilized egg. Following embryogenesis and a molt, the second-stage juvenile (J2) emerges from the egg and moves through the soil in search of a suitable host. Once the root is located, the J2 uses its stylet to pierce the cells adjacent to the vascular cylinder and to induce the formation of a specialized feeding site called a syncytium (28). The juvenile, now sedentary, draws nutrients and materials from the plant root for its growth and development and undergoes three additional molts before adulthood is reached (60).

The syncytium of the male degenerates, signaling an end to the feeding period, and the wormlike adult becomes mobilized and exits the root. The female, on the other hand, remains immobile and continues to feed. As its body continues to swell, the female eventually breaks through the surface of the root but remains attached to the feeding site. An SCN female generally produces between 40 to 600 eggs on average (46). Upon death, the females' body becomes a tough, protective covering (called a "cyst") that protects the eggs from desiccation and predation by microbes until favorable conditions arrive for hatch. Eggs can remain viable within a cyst for several years. On its own, SCN can move only a few centimeters in the soil in its lifetime. However, cysts can travel long distances by tillage and harvest equipment, wind, water, contaminated seed, and animals (35).

SCN development and reproduction are dependent on several factors, including soil temperature, moisture, texture, and pH (1,47,50,60). Soil temperature is of particular importance in the relationship between SCN and winter annual weed hosts. The optimal temperature for SCN development is 77° F (1) but higher or lower temperatures can slow SCN development (47). The time required for a second generation of SCN to be produced can range from 24 days at 73°F to 40 days at 64°F (56). Alston and Schmitt (1) reported that the time SCN takes to complete a lifecycle is influenced by the season. SCN required four weeks and 534 ± 24 degree days between 41 and 86°F ($DD_{41/86}$) during June and July. However, from July to August it took SCN three weeks and 429 ± 24 $DD_{41/86}$. During September and October four weeks were once again required to complete a lifecycle, and 372 ± 33 $DD_{41/86}$ were needed.

Weather station data from Indiana indicate that the period of overlap of high SCN activity and winter annual weed growth may be limited to a few weeks in early fall and late spring when soil temperatures favor both nematode activity and weed growth (6,42). These data suggest that soil temperatures in Indiana may be adequate for SCN to complete a life cycle in the fall and/or spring on compatible winter annual weeds when soybean is not present in the field and was recently confirmed by Creech et al. (12) (Fig. 2).

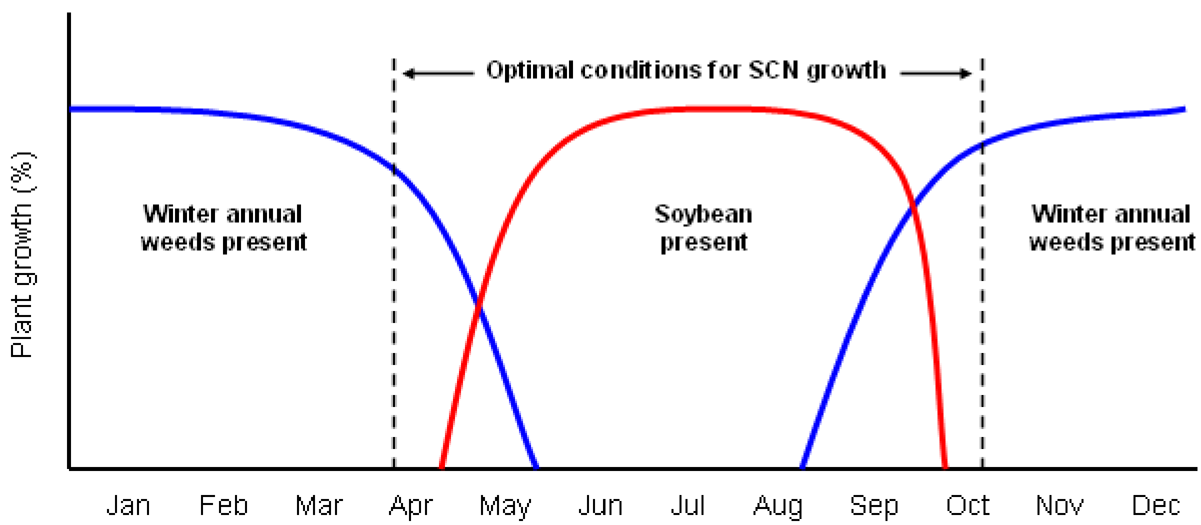

Fig. 2. Optimal conditions for SCN growth in relationship to soybean and winter annual weed growth.

Weeds as Alternative Hosts of SCN

SCN has a relatively broad host range, but its only major agronomic crop host is soybean. Riggs (41) reviewed the literature and compiled a list of 96 genera of Fabaceae (Leguminosae) and 50 non-legume genera representing 22 plant families that have been reported as alternative hosts of SCN. Several SCN host species are common winter annual weeds in Indiana. In a recent greenhouse experiment in Ohio, purple deadnettle (*Lamium purpureum* L.) (Fig. 3), henbit (*Lamium amplexicaule* L.) (Fig. 4), field pennycress (*Thlaspi arvense* L.) (Fig. 5), and shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik] (Fig. 6) were shown to support SCN reproduction (52). Earlier reports had identified common chickweed [*Stellaria media* (L.) Vill.] (Fig. 7) and smallflowered bittercress (*Cardamine parviflora* L.) (Fig. 8) as hosts to SCN (41). In addition, Creech et al. (12,17) has shown that SCN can reproduce on purple deadnettle and henbit in the field after soybean harvest in the fall in Indiana.


Fig. 3. Purple deadnettle is a strong alternative host to SCN.


Fig. 4. Henbit is a strong alternative host to SCN.


Fig. 5. Field pennycress is a moderate alternative host to SCN.


Fig. 6. Shepherd's-purse is a weak alternative host to SCN.


Fig. 7. Common chickweed is a weak alternative host to SCN.


Fig. 8. Smallflowered bittercress is a weak alternative host to SCN.

Potential Management Implications

Current integrated pest management (IPM) recommendations for fields infested with SCN include rotation to a non-host crop and use of SCN resistant soybean varieties (22,36). However, these guidelines may be inadequate if SCN populations can be sustained or increased on winter annual weeds when SCN-susceptible soybean is not present in the field (Fig. 2). Venkatesh et al. (52) reported that on susceptible soybeans SCN (race 3) cyst population densities were 366 per 450 cm^3 of soil. Purple deadnettle (510 per 450 cm^3), henbit (155 per 450 cm^3), field pennycress (73 per 450 cm^3), and shepherd's purse (1 per 450 cm^3) were also reported to support SCN reproduction. Earlier studies reported that common chickweed was an alternative host having and average of 6 cysts per pot (48) and smallflowered bittercress had at most 68 cysts per pot (40). Recent changes in crop production practices have created a favorable environment for the establishment and proliferation of winter annual weeds, yet many producers do not manage them specifically since their growth and development overlaps minimally with summer annual crops like soybean and corn. Creech et al. (13) surveyed 55 soybean cyst nematode (SCN) infested production fields across Indiana in March 2004 to assess broadleaf winter weed prevalence. The most frequently occurring weeds were common chickweed (87%), speedwell (*Veronica* spp.) (83%), buttercup (*Ranunculus* spp.) (58%), and henbit (53%). Henbit and wild garlic (*Allium vineale* L.) were present at the highest average densities, both occurring at greater than 50 plants/yd^2. Based on relative abundance indices, common chickweed and henbit were the most prevalent winter weeds in this survey. As a composite, winter weed hosts of SCN were found in 93% of fields and occurred at an average density of 151 plants/yd^2. No correlation existed between weed density and SCN egg counts. Frequency, uniformity, density, and diversity indices for individual weed species were generally higher in the southern region of Indiana than compared to the north. Thus, the region of highest risk for SCN reproduction and population increase on winter weeds in Indiana appears to be the southern part of the state. To date, this is the only known survey for the prevalence of winter annual weed hosts of SCN.

A subsequent survey of production fields in Indiana, Illinois, and Ohio was conducted to assess soybean cyst nematode (SCN) development and reproduction on henbit and purple deadnettle (17). This research showed that all growth stages of SCN were found to be associated with henbit and purple deadnettle at both fall and spring sample timings. SCN juveniles were generally found at highest abundance in the spring. SCN cyst and egg production was frequently observed and occurred to a much higher degree during the fall than the spring developmental period. The results of this survey indicate that management tactics designed to minimize the impact of winter weeds on SCN population density would probably be most effective if conducted in the fall. However, spring populations of winter annual weeds that are harboring SCN juveniles may result in additional SCN reproduction and population increase if the weeds are not controlled in a timely manner prior to planting.

The most common winter weed management tools utilized in no-till corn/soybean production systems in Indiana are herbicides and winter cover crops. Winter annual weeds can be effectively controlled with herbicides in the fall (23,29) or the spring (30,32) but the effect of weed removal timing on SCN population density is unknown. Optimal herbicide application timing may enable these winter annual weeds to serve as "trap crops" for SCN. In such a scenario, the weed would induce SCN egg hatch and root penetration, after which herbicides could be applied to kill the host plants (and thus the infective SCN juveniles) before SCN completes its reproductive cycle. A similar effect may be achieved if infective SCN juveniles are killed by cold winter temperatures when they enter winter weed roots at a time too late to reach maturity in the fall. However, Creech et al. (15) has shown that after hatching, SCN juveniles can survive for at least 20 days at 32°F inside the roots of a winter annual weed host and continue development when transferred to warmer temperatures. Therefore, in a field environment where the fall or spring alone may not be sufficient for SCN to complete a reproductive cycle on a winter annual weeds, the nematode may be able to reproduce by combining the fall and spring developmental periods.

Fall seeded cover crops also hold promise as a system to reduce winter weed growth and SCN population density. In corn/soybean production systems, research on weed suppression by fall-planted, spring-killed cover crops has generally focused on growth of summer annual weed species in the subsequent corn or soybean crop (9,18,24,49,59) with only 2 reports available of their influence on winter annual weeds (16,34). Nelson et al. (34) found that winter rye (*Secale cereale*) and annual ryegrass (*Lolium multiflorum* Lam.) controlled chickweed and henbit 66 to 86% while fall applied herbicides provided 99% control in Missouri. In the eastern cornbelt, research has shown that fall-seeded annual ryegrass or winter wheat (*Triticum aestivum* L.) had little effect on reducing henbit and purple deadnettle densities in Indiana (16). However, little is known about the ability of cover crops to suppress growth of other winter annual weed hosts.

A related approach to reduce SCN populations in soil would be to grow non-host plants that stimulate SCN egg hatching. Recent evidence showed that root exudates and plant residues of several non-host plants stimulated SCN egg hatching in vitro and under greenhouse conditions (39). The most effective of all species tested in reducing SCN populations was annual ryegrass, a widely adapted winter annual species that may be used as a cover crop for erosion prevention, nutrient and moisture management, and weed suppression (2). Root exudates of annual ryegrass have been reported to increase SCN egg hatching by 47% compared to that of soybean (39).

Limited research has been conducted to address the effects of winter weed management tactics on SCN dynamics and reproduction in the field. Research has found that Indiana fields with relatively low henbit and purple deadnettle densities (less than 75 plants/yd^2), SCN population density was reduced by crop rotation and use of an SCN-resistant soybean variety; however, SCN density was not influenced by winter annual weed management when winter weed management operations were conducted in mid- to late October (16). Nelson et al. (34) reported that SCN population density increased from fall to spring in continuous, no-till soybean without fall applied herbicides or cover crops and remained stable when fall applied herbicides were used to control winter annual weeds. SCN population densities were not reduced in cropping where non-host crops were grown regardless of how winter weeds were managed. Venkatesh et al. (53) reported that there were no differences in SCN egg populations due to removal times in the first year of a two-year study. Second-year results indicated that SCN egg populations were reduced significantly when purple deadnettle was removed in May compared to earlier removal dates in September and October. These results and other studies suggested that the timing of winter annual weed removal will play an important role in influencing SCN population density and requires further research.

Future Research on the Winter Annual Weed and SCN Interaction

A number of potential areas exist for additional research into the interaction between winter annual weeds and SCN. First, management of winter annual weeds in low weed density fields failed to influence SCN population density (16). However, research in the greenhouse has indicated that SCN reproduction on winter annual weeds is dependent on weed density (14). Therefore, field research should be conducted in order to determine what density of winter annual weeds can increase SCN populations density. Future research should be directed toward assessing the effect of winter annual weed management on SCN population density in fields with these high weed densities. Second, much of the work regarding heat-unit accumulation in the development of SCN has been conducted during the growing season on soybean. Temperature and time requirements for SCN to develop on winter annual weeds during the fall and spring may be different than that of soybean. Third, the majority of SCN reproduction occurs in the fall (17) but the winter annual weed control operations probably need to be implemented during the summer or early in the fall to disrupt the lifecycle of SCN. The optimal timing of winter annual weed removal in the fall is unknown. Therefore, more research is needed to determine if weeds should be removed in early or late fall or if winter annual weeds can be controlled in early spring to minimize SCN population densities. Fourth, herbicides vary with respect to the speed at which they kill plants. A delay in plant death may enable SCN to continue to develop and complete a reproductive cycle after herbicide application. Future research should be directed toward assessing the influence of different herbicide chemistries and application timings on the interaction between winter annual weeds and SCN. Fifth, it is not uncommon to observe winter annual weed growth in no-till or conventional-till soybean fields during the latter part of spring or early fall. Thus, the influence of tillage on the interaction between SCN and winter annual weeds is unknown. Finally, greenhouse studies have shown that annual ryegrass can induce premature hatching and subsequent death of SCN (39). More research is needed on the effect of annual ryegrass cover crops on their ability to suppress SCN population densities in the field.

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