2010 Innovations in Chemical Control

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Nematicides are the primary means of nematode control for manyproducers in the U.S. During the 1940s and 1950s, soil fumigation was commonly used tomanage nematodes in cotton, but difficulty in application, expense, and environmental andhuman health risks resulted in the removal of most of these chemicals from the market.During the next 30 years, carbamates and organophosphates largely replaced soilfumigants as nematicides in cotton. These materials were attractive because they were lowin phytotoxicity and could be applied at planting. In addition, many of these chemicalswere also effective against insects, so producers could accomplish both nematode and insectsuppression with the same pesticide. Recently, however, human health and environmentalconcerns have resulted in the suspension of many of insecticide/nematicides, and today only two remain labeled for use on cotton. Few new chemicals that can be used for nematode control in cotton have been forthcoming, and growers now face increasingly severe nematode problems in the absence of many of their historically effective nematicides. Environmental concerns and focus on safety have resulted in nematode managementstrategies that either utilize existing nematicides more efficiently or rely on chemicals used at lower rates than those presently registered.

KEYWORDS: nematode, nematicide, nematode control, abamectin, harpin, thiodicarb

Nematicides – A Brief History

Fumigant nematicides. Prior to WW II, research on chemicals specifically targeted to plant-parasitic nematodes was focused on high value crops such as pineapple (*Ananas comosus*) (Godfrey, 1935; Johnson and Godfrey, 1932) where nematodes had been "discovered" to be a contributing factor to yield and quality reduction. At this point, the impetus for using chemicals to control nematodes was driven mainly by the availability of large quantities of surplus chloropicrin that remained at the close of WW I rather than by yield and quality concerns alone (Johnson and Feldmesser, 1987). The need to dispose of chloropicrin and the fact that it was a relatively effective soil biocide fueled considerable study of nematodes as plant pathogens, basic soil ecology, and the technology needed to apply volatile chemicals to soil. Fortunately, by the time government stores of surplus chloropicrin were exhausted by the late 1930s, the concept of nematicide application as a means of mitigating nematode damage to crops had become established, and a search for new, effective chemicals to replace chloropicrin was well underway. In 1941, a practical method for using another volatile biocide (methyl bromide) was reported (Taylor and McBeth, 1941). Methyl bromide was extremely effective across a range of soil borne organisms including nematodes, fungal pathogens, and many weeds, but it was highly toxic and rather expensive to use, limiting its use to only the highest value crops. Within the next few years, however, two new chemicals that were less expensive and much easier to apply were discovered. The first of these was a product obtained from the Shell Chemical Corporation known as D-D (a mixture of 1,3-dichloropropene and 1,2-dichloropropane) (Carter, 1943). The second was a related material, ethylene dibromide (EDB) that was marketed by both Shell and Dow Chemical Companies (Christie, 1945). Both materials were much less volatile than methyl bromide and were highly effective against nematodes, but were less efficacious against soil borne fungal pathogens and weeds. In addition to providing an effective means of managing nematode damage to various crops, these materials were perhaps most important in demonstrating to the general public the role of nematodes as plant pathogens (Johnson and Feldmesser, 1987).

In 1954, 1,2-dibromo-3-chloropropane (DBCP) was reported as having nematicidal properties (McBeth, 1954; Raski, 1954). This material provided a considerable improvement over previously used nematicides because it was effective at relatively low application rates (making it less expensive to use), and was much less phytotoxic and less volatile than either D-D or EDB. DBCP launched a new era of nematicide use because it could be applied either before or after planting on an array of crops . The introduction of DBCP into the marketplace as Nemagon® (Shell Chemical Co.) or Fumazone® (Dow Chemical Co.) solidified the concept of nematicide application as a primary strategy in nematode management in agronomic crops including cotton. Unfortunately, environmental and human health concerns resulted in its elimination from the marketplace in the mid-1970s. A second material with nematicidal properties, sodium methyl dithiocarbamate (metam sodium), was reported in 1956 (Lear, 1956). Metam sodium (Vapam®) releases methyl isothiocyanate as it degrades, a chemical that is active against nematodes as well as certain soil borne fungal pathogens and weeds. All of the fumigant nematicides mentioned above were labeled for use in cotton. Today only Vapam and a related product, K-Pam® (potassium N-methyldithiocarbamate), chloropicrin, and 1,3-dichloropropene (Telone II®), remain on the market, although limited use of methyl bromide still occurs with a few high value crops under a special critical use exemption.

Non-fumigant nematicides. A second category of chemicals with toxicity to nematodes was reported during the 1960s and 1970s primarily as a result of evaluations to discover more effective insecticides. Two general chemical classes: organophosphates and carbamoyloximes (carbamates) were recognized as having toxicity against nematodes as well as insects (Christie and Perry, 1958; Jenkins and Guengrich, 1959; Weiden et al., 1965). These insecticide –nematicides were less volatile than the nematicides that were being used at the time. They were also easier to apply, and they were less phytotoxic. The first of these products to be used were the organophosphates thionazin and dichlofenthion, VC-13, which were marketed for nematode control in turf and ornamentals. In the ensuing 30 years, numerous organophosphates and carbamates were registered as nematicides, and many were labeled for use on cotton. Today, however, only two of these chemicals, aldicarb (Temik®) and oxamyl (Vydate®), remain available for nematode control in cotton. In the U.S. three nematodes are considered of major economic importance in cotton: the southern root-knot nematode (*Meloidogyne incognita*), the reniform nematode (*Rotylenchulus reniformis*), and the Columbia lance nematode (*Hoplolaimus columbus*) (Kirkpatrick and Rothrock, 2001). Root-knot nematodes can be found associated with sandy soils throughout the Cotton Belt. The reniform nematode is found throughout most of the southeastern and southern states, and appears to favor soils containing greater amounts of silt and clay (Koenning et al., 1996; Robinson et al., 1987; Still and Kirkpatrick, 2006). Columbia lance nematodes are restricted in incidence currently to extremely sandy soils in the southeastern coastal plain. Although generally one species is predominant in a particular field, it is not uncommon to find two or, in some cases, all three species at economic levels in the same field. Regardless of the species, when population densities are above economic thresholds, yield suppression ranging up to 50% in some areas within individual fields can occur (Koenning et al., 2004). At present, no cotton cultivars are available commercially with appreciable resistance to either *R. reniformis* or *H. columbus* (Robinson and Percival, 1997; Bowman and Schmitt, 1994). Although numerous breeding lines with high levels of resistance to *M. incognita* have been reported, only a few cultivars with moderate levels of resistance have been released commercially (Koenning et al., 2004). Consequently, nematicide application is currently the main strategy for nematode suppression in fields where population densities exceed economic thresholds. Almost 50 years ago, Hollis (1958) suggested that the ideal nematicide should be efficacious in the soil for several months, non-phytotoxic and low in mammalian toxicity, and be free from residual properties that might render food crops unfit for consumption. To date, this ideal chemical has not been discovered. In the U.S. only a limited number of chemicals are labeled for use in cotton.

Current Nematicide Use Strategies

Conventional strategies. In the southeastern states, and to a limited degree in the mid southern and western regions, preplant soil fumigation with Telone II has been a standard practice among cotton growers in fields where severe nematode damage is expected. Disadvantages of this strategy include the difficulty and relatively high per hectare cost for fumigation and the fact that the fumigant must be applied at least two weeks pre-planting, many times under unfavorable soil and weather conditions. In addition, air quality concerns in some areas limit the quantity of Telone II that may be applied in a given year. When Telone II is applied properly, significant yield responses are generally seen (Figure 1). The second and more widely used strategy is the application of the non-fumigant insecticide-nematicide, Temik, in the furrow at the time the seeds are planted. Temik is more convenient to apply and less expensive on a per hectare basis than soil fumigation, but yield responses may be less consistent (Figure 2). Likely due to its rather broad spectrum of efficacy that includes both nematodes and certain early-season insect pests, Temik usage has dramatically increased in U.S. cotton over the last 15 years, and it is used on 20 to 30% of the acreage across the Cotton Belt each year (Koenning et al., 2004).

Less conventional strategies. Although nematicides have historically been applied either pre-planting or during the planting operation, the low degree of phytotoxicity of both Temik and Vydate allows them to be applied post-planting. While the high mammalian toxicity of Temik precludes foliar applications, some growers have found that nematode suppression can be improved by a second soil application, applied as a side dressing four to six weeks after emergence (Baird, et al., 2000). Generally, this additional application of Temik is delivered into furrows (4 to 6 cm deep) that are parallel to the row 10 to 15 cm away from the plants. Vydate, which is marketed both as a foliar insecticide and as a nematicide, has been shown to be basipetally translocated in a number of crop species (Radewald et al., 1970; Santo and Bolander, 1979). Recent investigations indicate that foliar applications to cotton early in the growing season in combination with at-planting application of Temik may improve nematode suppression above that achieved with Temik alone (Lawrence and McLean, 2000; Lawrence and McLean, 2002). Biorational approaches to nematode control have received only limited attention.

Recently, a protein from *Erwinia amylovora* (harpin) with the reported ability to elicit a resistant response in certain plant species (Wei and Beer, 1996) has been suggested as a means to enhance crop growth, development, and pest resistance. Studies in cotton indicate that reproduction of *Meloidogyne incognita* may be slightly lower in harpin-treated plants (Table 1), but yield responses have been disappointing (Bednarz et al., 2002). A second interesting biorational approach involving genetic engineering of the cotton plant has been suggested (Atkinson et al., 2003). Aldicarb in the soil solution at rates that are usually applied results in cholinesterase inhibition leading to paralysis and ultimately nematode mortality (Spurr, 1982). However, at much lower concentrations (21 pM), aldicarb acts as a chemoreception inhibitor in nematodes (Winter et al., 2002). Certain peptides have been shown to elicit this same response, and development of plants that produce these proteins in roots has been suggested as a way to suppress nematode infection. Unfortunately, the concept of developing plants that produce aldicarb-like substances is likely not prudent from a human or animal health perspective.

Very recently, a strategy that utilizes low dosage application of nematicidal chemicals to cotton seed as a seed treatment has shown considerable promise for providing a limited degree of nematode control. Avermectins, macrocyclic lactones derived from *Streptomyces avermictilus*, are extremely toxic to nematodes and certain insects (Putter et al.,1981). These chemicals are widely used as anthelminthics in animals, and as foliar insecticides, and they have been studied as nematicides (Sasser et al., 1982; Garabedian and Van Gundy, 1983). Unfortunately, their utility as soil-applied nematicides has been limited due to expense, low water solubility, and their tendency to adsorb to soil particles (Bull et al., 1984). However, application of certain avermectins (abamectin) as a seed dressing has shown promise for nematode suppression in cotton seedlings (Monfort et al., 2006). This product (Avicta Complete Pak®) was labeled for use in U.S. cotton in 2006 as a component of a seed treatment that also includes an insecticide and a fungicide. A second seed treatment that utilizes a carbamate (thiodicarb) as the nematicidal component (Aeris®) will be available for cotton in 2007. Seed treatment may suppress nematode infection for a limited time early in the growing season (Figure 3; Table 2), a critical growth period for the cotton crop (Penteado et al., 2005). Although the concept of applying nematicides to seed holds considerable promise as a part of an overall strategy, seed treatment alone will likely not be sufficient to avoid yield loss in fields where nematode population densities are high. Improved efficiency in the application and placement of existing nematicides has also been suggested as a means of lowering production costs and environmental risks. Precision farming technology holds promise as a means of applying nematicides in a site-specific manner within individual fields rather than using the current approach of one rate applied field wide (Evans, 2002). Since the spatial variability of nematodes within fields is generally high, identification of areas within fields that are at a high risk for sustaining economic crop damage based on nematode population density and other edaphic factors would allow focused nematicide treatments to be applied (Monfort et al., 2007). Unfortunately, attempts to develop this approach have shown only limited practicality largely due to the difficulty and expense required for nematode sampling (Wheeler et al., 1999; Wyse-Pester et al., 2002; Wrather et al., 2002). Current investigations into using aerial imagery or mobile soil electrical conductivity meters to define potential problem areas appears promising and may lead to improved strategies for nematicide placement in the near future (Kirkpatrick et al., 2006; C. Overstreet, *personal communication*). Nematicides continue to be the primary means of managing nematode-induced yield suppression in cotton in the U.S. Growers are facing a dilemma. While the number of highly effective nematicides labeled for use in cotton has declined dramatically over the past 30 years, nematode incidence and severity across the Cotton Belt are at an all-time high. Production costs continue to increase, and environmental and health concerns have restricted or eliminated the use of numerous products that were both economical and effective. In the face of this change, it will be imperative that more sustainable, environmentally appropriate approaches to nematode management in the crop be developed.

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Table 1. Reproduction of *Meloidogyne incognita* on harpin-treated plants in a growth chamber.

	Eggs/Root System	Eggs/Adult Female[z]
Harpin (Messenger®)	**1,690 b**	**149 b**
Control	**22,152 a**	**318 a**

[z]Based on egg counts from 10 individual egg masses.

Table 2. Lint yield and *Rotylenchulus reniformis* population density 30 days after planting.

	Nematodes/500 cm^3	Lint
		-- kg/ha --
Insecticide alone	**2,989 a**	**1,199 b**
Aeris	**2,556 a**	**1,245 ab**
Temik (840 g/ha)	**2,500 a**	**1,357 a**

Figure Legends

Fig. 1. Cotton lint yield in Arkansas cotton field trials (2000-2004) with and without soil fumigation with Telone II at 29 liters/ha.

Fig. 2. Cotton lint yield in small plot field tests (2005 and 2006) with or without Temik application at planting at 5.6 kg/ha. Letters indicate individual field sites.

Fig. 3. Comparison of abamectin seed treatment and Temik soil treatment in microplots. **A.** Number of *Meloidogyne incognita* in roots of cotton at 12 days after planting. **B.** Gall ratings at harvest.

Figure 1.

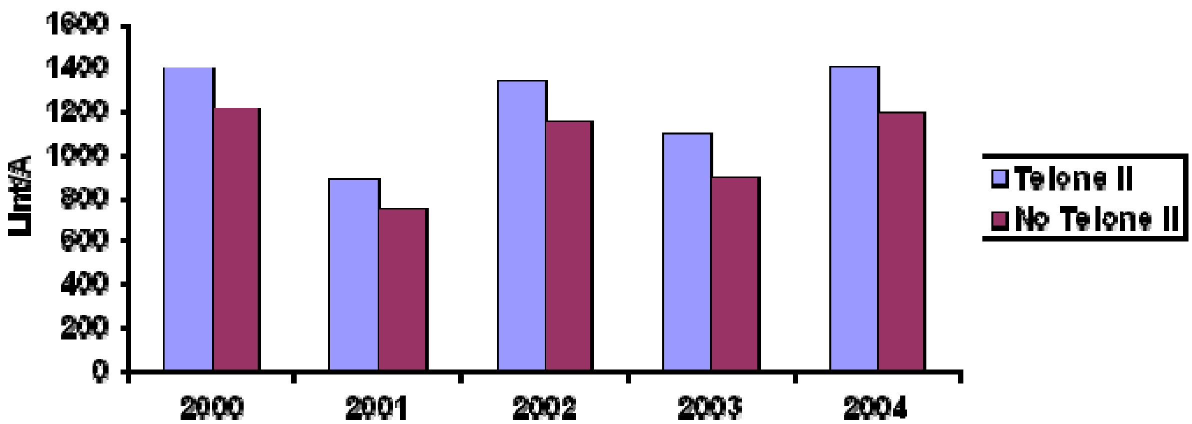


Figure 2.

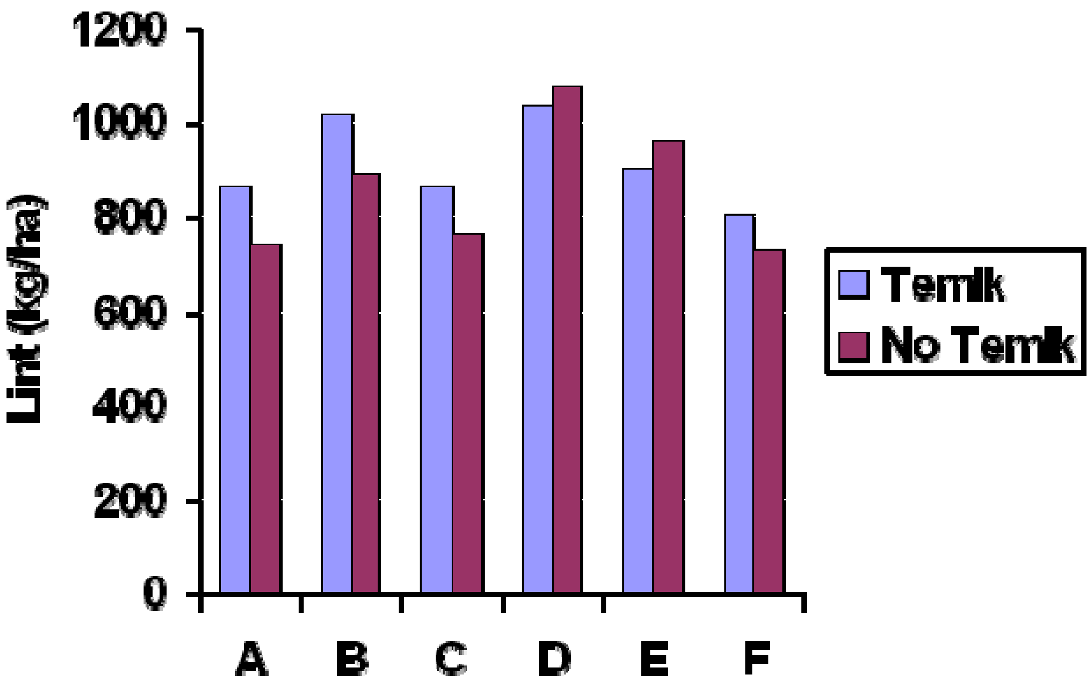
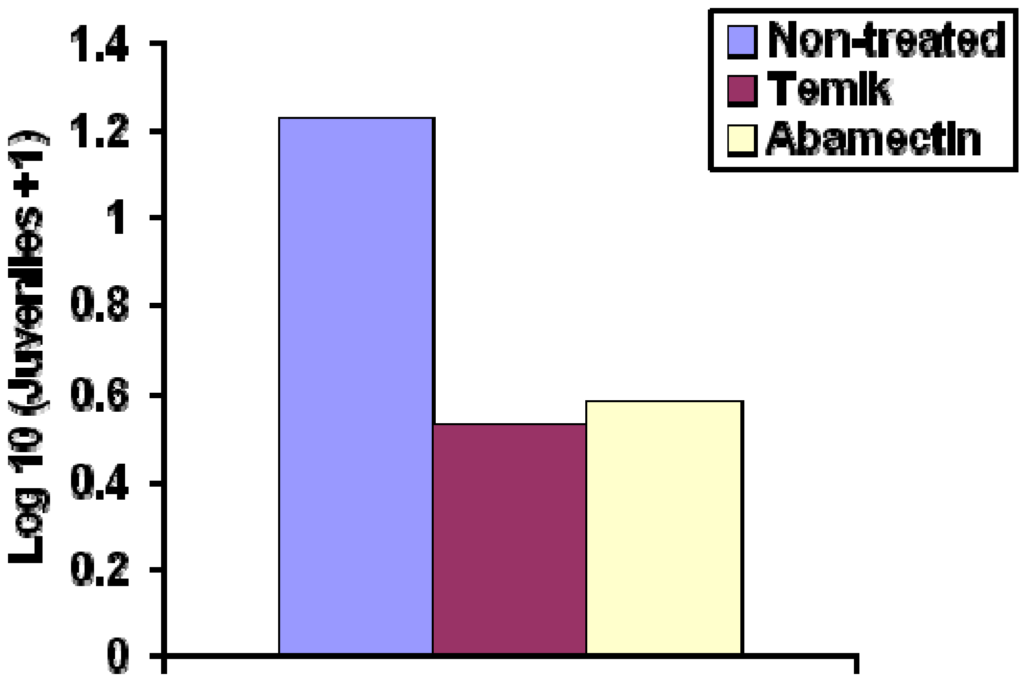


Figure 3.


Non-treated
Temik
Abamectin
Log 10 (Juveniles +1)
1.4
1.2
1
0.8
0.6
0.4
0.2
0

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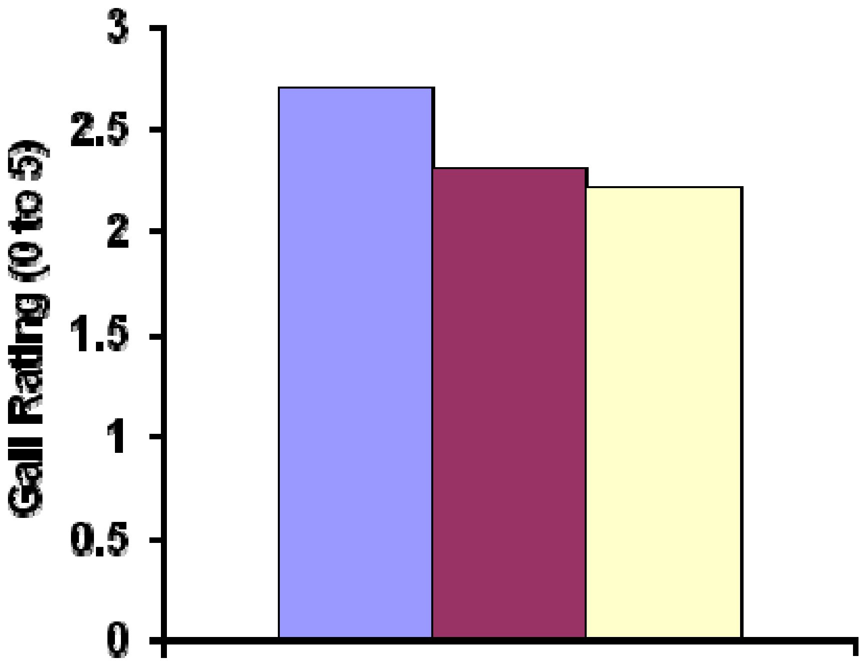
Gall Rating (0 to 5)
3
2.5
2
1.5
1
0.5
0

B