REVIEW
ROTYLENCHULUS RENIFORMIS IN COTTON: CURRENT METHODS OF MANAGEMENT AND THE FUTURE OF SITE-SPECIFIC MANAGEMENT

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ABSTRACT

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The reniform nematode, *Rotylenchulus reniformis*, is currently one of the most limiting factors to cotton production in the United States. With no available commercial host plant resistance, options for management of *R. reniformis* are limited to the use of rotations with non-hosts and the use of nematicides, each of which varies greatly in cost-savings and effectiveness. Multiple research groups are currently pursuing the goal of site-specific management for *R. reniformis* in cotton. Site-specific application is used for a wide variety of agricultural practices, and successful programs for other species of nematodes in cotton, such as *Meloidogyne incognita* and *Hoplolaimus columbus*, are currently in use. Within this manuscript, future possibilities for the use of site-specific management for *R. reniformis* in cotton as well as potential limitations of current techniques are discussed.

Key words: Cotton, crop rotation, *Rotylenchulus reniformis*, site-specific management.

RESUMO

Moore, S. R., and K. S. Lawrence. 2012. *Rotylenchulus reniformis* en algodón: métodos actuales de manejo y futuro del manejo sitio-específico. Nematropica 42:227-236.

El nematodo reniforme *Rotylenchulus reniformis* es actualmente uno de los factores mas limitantes en la producción de algodón en los Estados Unidos de América. Comercialmente no se encuentra disponible resistencia en plantas hospederas, por lo tanto el manejo de *R. reniformis* se limita al uso de rotaciones con plantas no hospederas o al uso de nematicidas, los cuales varian considerablemente en costo y efectividad. Actualmente múltiples grupos de investigación están en busca de estrategias de manejo sitio-específicas para *R. reniformis* en algodón. Estas estrategias son usadas en una gran variedad de prácticas agrícolas, y actualmente son empleadas en exitosos programas para otras especies de nematodos en algodón, tales como *Meloidogyne incognita* y *Hoplolaimus columbus*. En este manuscrito se discuten las futuras posibilidades para el uso de estrategias sitio-especificas de *R. reniformis* en algodón, así como potenciales limitaciones de las técnicas actuales.

Palabras clave: algodón, rotación de cultivos, *Rotylenchulus reniformis*, manejo sitio-específico.

Cotton, *Gossypium hirsutum* Linnaeus, is one of the most economically important crops in the United States. In 2010, cotton was grown in 17 states with 11 million acres devoted to cotton production valued at more than $7.3 billion (USDA-NASS, 2011).

The reniform nematode, *Rotylenchulus reniformis* Linford & Oliveira, is a semi-endoparasite of roots that occurs in tropical and sub-tropical regions (Robinson *et al.*, 1997) and is a major pathogen affecting U. S. cotton. Currently, *R. reniformis* can be found in 11 of the 17 cotton producing states and is estimated to have caused a loss of nearly 2% annually in the past decade (Blasingame *et al.*, 2002 – 2012).

Rotylenchulus reniformis is easily introduced into cotton fields on contaminated equipment and other means of soil transport. Once there, it can be spread throughout the field by tillage and water flow (Monfort *et al*., 2008; Moore *et al*., 2011a); however, in no-till systems, *R. reniformis* can spread independently both horizontally

and vertically (Moore *et al.*, 2010a). Vertical distribution has been well documented at depths of up to 1.5 m (Lee *et al.*, 2002; Moore *et al.*, 2010a; Robinson *et al.*, 2005a; Westphal & Smart, 2003; Westphal *et al.*, 2004), and populations below the plow layer can greatly affect cotton yields (Newman & Stebbins, 2002; Robinson *et al.*, 2005b).

Currently, there are no commercial cotton cultivars with resistance or consistent tolerance to *R. reniformis* (Usery *et al.*, 2005; Robinson, 2007). As such, management options for *R. reniformis* fall into two major categories: pesticides and crop rotation. There are many forms of pesticides available for the management of *R. reniformis*. Each varies in effectiveness and each has its limitations. Fumigants such as 1,3-dichloropropene (Telone II) and metam sodium (Vapam) are generally highly effective for management of *R. reniformis* (Kinloch & Rich, 2001; Koenning *et al.*, 2007; Lawrence *et al.*, 1990; Rich & Kinloch, 2000). They are often limited by cost, high risk to applicators, special application equipment, soil texture, and temperature and moisture requirements.

An assortment of granular pesticides have been proven effective for the management of *R. reniformis*, including aldicarb (Temik 15G) (Lawrence *et al.*, 1990; Lawrence & McLean, 2000, Rich & Kinloch, 2000), fenamiphos (Nemacur) (Koenning *et al.*, 2007; Lawrence *et al*., 1990), and terbufos (Counter) (Lawrence *et al.*, 1990). Of the granular pesticides, aldicarb has been the most widely used in cotton production, and its continual use has resulted in reports of enhanced degradation by soil microbes thus decreasing its overall efficacy (Lawrence *et al.*, 2005). Furthermore, the future of this pesticide is currently unknown due to the discontinuance of its production (Bayer CropScience, 2010). Similarly, fenamiphos is no longer labeled for use in the United States (EPA, 2002), and terbufos is not currently labeled for use in cotton production.

Seed applied pesticides such as abamectin and thiodicarb have recently become widely used in cotton production as a part of Avicta Complete Cotton and Aeris Seed Applied System, respectively, and have been reported to provide adequate management of *R. reniformis* (Faske & Starr, 2006; Lawrence & Lawrence, 2007). Their protection of the root is limited (Faske & Starr, 2007) as is their ability to provide adequate protection against high populations of *R. reniformis* (Moore *et al*., 2010b).

Oxamyl (Vydate C-LV) is a foliar applied pesticide that also provides adequate management of *R. reniformis*, often in conjunction with previously mentioned pesticides (Baird *et al.*, 2000; Lawrence & McLean, 2000), but has been reported to be less effective in dry conditions (Koenning *et al.*, 2007). Additional options for *R. reniformis* management in the form of biological organisms, such as *Bacillus firmus* (Poncho/VOTiVO) and *Paecilomyces lilacinus* strain 251 (Nemout) as seed applied formulations (Castillo *et al*., 2011), have been reported to have efficacy against *R. reniformis*. Furthermore, there are multiple known nematophagous fungi with high levels of effectiveness in greenhouse studies (Wang *et al*., 2004; Castillo *et al*., 2009) that could prove useful in the future. Overall, the number of pesticides for the management of *R. reniformis* is decreasing, resulting in increased challenges for producers.

Crop rotation to non-hosts, such as corn or peanuts or highly resistant varieties of soybean, is also an effective strategy for the management of *R. reniformis*. A one year rotation with corn and resistant soybean effectively increases cotton yields (Davis *et al*., 2003; Moore *et al*., 2010c); however, populations of *R. reniformis* quickly rebound to pre-rotational crop levels by mid-season. A two year or longer rotation with corn or resistant soybean or a one year or longer rotation with peanuts can result in *R. reniformis* populations remaining below current economic thresholds throughout the subsequent cotton crop (Stetina *et al.*, 2007; Moore *et al*., 2010c). Many native weed species are host of *R. reniformis* to some degree and can confound the aforementioned positive effects of crop rotation if not properly controlled (Davis & Webster, 2005; Jones *et al*., 2006; Lawrence *et al.*, 2008; Wang *et al*., 2003).

The methods currently used to manage *R. reniformis* in cotton can be economically beneficial if utilized intelligently and with forethought. For a problem that is consistently increasing, further management strategies are needed. Site specific, or precision, management (SSM) is a concept that is increasingly utilized since being made possible by the integration of global positioning systems (GPS) technologies into agriculture. The use of SSM based on soil variability as a strategy to enhance the management of *R. reniformis* has developed into a subject of great interest in recent years. In this review, the current methods of zone delineation for SSM and their uses will be discussed along with the potential for use of known factors affecting *R. reniformis* and its

interaction with cotton. The pitfalls of SSM in regards to its use for *R. reniformis* management also will be addressed, as will an evaluation of the feasibility of using current methods of SSM for *R. reniformis*. Finally, we will determine what information is still required to facilitate a workable guideline for implementing SSM for *R. reniformis*.

The delineation of management zones for SSM based on soil variability has been a topic of research for decades. A management zone can be defined as a subregion of a field that expresses a homogeneous combination of yield limiting factors for which a single rate of a specific crop input is appropriate (Doerge, 1999). The development of management zones requires the use of some form of geostatistical analysis. There are many different methods of geostatistical analysis, both descriptive and predictive, that can be used alone or in combination, depending on the situation. Descriptive methods of geostatistical analysis allow for the detection and quantification of the major scales of spatial variability (Goovaerts, 1998). Examples of such descriptive methods include the experimental correlogram, which plots the estimated correlation coefficients of one variable as a function of the separation distance, and the experimental semivariogram, which plots the semivariances of ordered data versus distance (Goovaerts, 1998). Predictive methods are utilized in the estimation of soil properties at unsampled places between or near collected data points. Examples of predictive methods of geostatistical analysis include ordinary kriging, which estimates the value of an unsampled location as a linear combination of neighboring observations, and factorial kriging, which estimates and maps different sources of spatial variability identified by experimental semivariograms (Wackernagel 1988, 1995; Goovaerts, 1992).

Prescription maps began development based on soil type (Carr *et al*., 1991) or topography (Fiez *et al*., 1994). Further research has developed prescription maps on a collection of characteristics including soil type, soil color, topography, yield, aerial photos, and producer experience (Ostergaard, 1997; Fleming *et al*., 2004). The use of soil apparent electrical conductivity (EC) has become one of the most frequently used methods of management zone delineation based on soil variability. Apparent electrical conductivity has been found to correlate highly with soil texture (Williams & Hoey, 1987). It also relates closely with a variety of other characteristics including: cation exchange capacity and exchangeable Ca and Mg (McBride *et al*., 1990), water content (Kachanoski *et al.*, 1988), soil organic C (Jaynes, 1996), herbicide behavior in soil (Jaynes *et al*., 1994), depth to claypans (Kitchen *et al.*, 1999), and crop yield (Sudduth *et al.*, 1995; Heermann *et al*., 1999).

The geostatistical analysis of soil properties and the subsequent delineation of management zones have proven effective in a variety of situations worldwide. Casa & Castrignano (2008) demonstrated the spatial relationships between soil and crop variables of durum wheat in Italy. Rab *et al*. (2009) utilized geostatistical modeling of plant-available water capacity and related soil properties to delineate management zones for the enhancement of grain yields in Australia. Liu *et al.* (2006) explored the possibilities of combining ordinary kriging with soil map-delineation to enhance the interpolation of soil properties in a paddy rice/sugarcane rotation in Taiwan. Lopez-Lozano *et al.* (2010) successfully linked leaf area index with soil properties for precision management of abiotic stress of corn in Spain. In the U. S., management zones based on soil characteristics have been used to predict grain yields (Fraisse *et al.*, 2001) and determine the risk of iron chlorosis in maize (Kyaw *et al.*, 2008).

The use of geostatistical analysis and management zone delineation also has recently been developed for the management of the Columbia lance nematode (*Hoplolaimus columbus*), the root-knot nematode (*Meloidogyne incognita*), and the ring nematode (*Criconemella* spp.) (Khalilian *et al.*, 2001; Khalilian *et al.*, 2002; Khalilian *et al.*, 2003; Monfort *et al.*, 2007; Ortiz *et al.*, 2007; Ortiz *et al.*, 2008; Wolcott *et al.*, 2004; Wolcott *et al.*, 2005). Khalilian *et al.* (2003) reported a 5% yield increase using either variable rate aldicarb or 1,3-dichloropropene for Columbia lance management with a 34% and 78% reduction of input, respectively. Monfort *et al.* (2007) observed that the combination of the initial populations of root-knot nematodes and the sand content of the soil explained 65%, 86%, and 83% of the variation in cotton yield over a three-year period, respectively. Similarly, Ortiz *et al.* (2007) observed that a model of root-knot nematode risk of a field over a specific threshold value could be produced through logistic regression using soil electrical conductivity as a predictor variable. Furthermore, it was determined that the use of variable rate application of nematicides could be effectively employed to manage root-knot

nematodes in cotton (Ortiz *et al.*, 2008).

Although there are several successful examples of site-specific management of nematodes, there are studies that address certain pitfalls of this technique. Wyse-Pester *et al.* (2002) conducted a study to determine the scale of sampling required to obtain correlated observations of density in order to reduce sampling costs for three species of nematodes on corn. The results of the study indicated that correlations between nematode density and soil attributes were inconsistent between field and species, and thus the cost of sampling was not reduced. Similarly, Evans *et al.* (2002) found that coarse sampling grids, which are required to make SSM a commercially viable option for the management of potato cyst nematodes (*Globodera pallida* and *G. rostochiensis*), are likely to produce misleading population distribution maps resulting in yield penalties. Farias *et al.* (2002) were able to construct an accurate distribution model of *R. reniformis* within a cotton field; however, the number of sampling points used (64 points within a 48 x 32 m area) would be cost prohibitive in a commercial setting. In a study assessing sampling grid size for variable rate application of nematicides for the management of *R. reniformis*, Ellis *et al*. (2004) found that fewer rate changes occurred with increasing grid size. This relationship has one of two possible consequences. The first is increased input of nematicides where they are not needed, which would result in a cost penalty. The second consequence would be not applying nematicides where needed, which would result in a yield penalty.

Technological pitfalls are also a possibility in the development of site-specific management. Choosing the correct analysis of spatial data is vital to producing accurate prescription maps. In a study of the accuracy of interpolating elevation data, a measurement commonly used in conjunction with EC for management zone delineation, Weng (2006) determined that accuracy was subject to a number of interpolation parameters that may significantly improve or worsen the accuracy. Similarly, it has been reported that apparent soil electrical conductivity is affected by soil transient properties such as volumetric soil water content and exhibits large changes throughout the season (McCutcheon *et al.*, 2006). Factors such as these can result in unreliable data and must be considered during management zone creation.

To create management zones within a field for *R. reniformis*, the factors of influence must first be characterized through quantitative research and then the data can subsequently developed into a useable form. As was discussed earlier, soil texture distribution can be easily measured within a field by utilizing soil apparent electrical conductivity and has been used in management strategies for other species of nematodes. Consequently, this factor has been investigated as a starting point for zone delineation for *R. reniformis*. While *R. reniformis* is known to exist and cause damage in a wide variety of soil types (Gazaway & McLean, 2003), some research has suggested that *R. reniformis* is more prevalent in fine-textured soils (Robinson *et al*., 1987; Starr *et al*., 1993; Monfort *et al*., 2008). Other research on the effects of soil type on *R. reniformis* populations has suggested that the productivity of the soil, not specifically soil texture, is the driving force behind population development (Koenning *et al*., 1996; Herring *et al*., 2010) as well as response to nematicides (Overstreet *et al*., 2007, 2011, 2012).

Another consideration for zone delineation is initial populations of *R. reniformis* and economic damage threshold values. More often than not, management decisions and subsequently economic threshold values are based on post-harvest nematode sampling. Although little is known about the overwinter survivorship of *R. reniformis*, it has been observed that overwinter survivorship was lowest in areas of high sand content and increased with increasing clay content (Still & Kirkpatrick, 2006). Studies of overwinter survivorship on *Meloidogyne incognita* have suggested that population density and cultural practices have the greatest impact on overwinter survivorship (Ferris, 1985). Studies have shown that *R. reniformis* populations are adversely affected by post-harvest conventional tillage compared to non-tillage and ridge tillage (Cabanillas *et al.*, 1999). Economic thresholds are established based on the relationships between the degree of control and cost and nematode densities and crop value (Ferris, 1978). Current thresholds are established on a state-by state basis, but it has recently been suggested that different economic thresholds be considered based on soil type and productivity (Moore *et al.*, 2011b).

Studies exploring the possibilities of SSM and variable rate nematicide applications for *R. reniformis* have been conducted in recent years. Variable rate application based on populations of *R. reniformis* have been conducted with the fumigant nematicides 1,3-dichloropropene and metam sodium with promising results (Lawrence

et al., 2002; Ellis *et al.*, 2005). Farias *et al*. (2002) created a risk-benefit analysis for the treatment of *R. reniformis* in a Brazilian cotton field by utilizing geostatistical methods to interpolate population distribution over short distances (4-6 m). Another tool in development is the use of remotely sensed hyperspectral data to detect stress levels in cotton. Doshi *et al.* (2010) conducted a study comparing hyperspectral reflectance of cotton plants grown in microplots to *R. reniformis* populations in the plant rhizosphere and determined that this method could accurately estimate *R. reniformis* populations affecting the cotton plant. The use of remote sensing to detect cotton plant stress due to issues with subsurface drip irrigation has also illustrated this tool's ability to detect differences in cotton response to stress in field settings (Fulton *et al*., 2008).

The successful use of site-specific management for *R. reniformis* on cotton is dependent on the resolution of several issues. The first and most important issue is to what spatial scale (single field, soil region, state, etc.) can general recommendations be developed and be reliable? Second, what parameters, or combination of parameters, will provide the most accurate measure of economic risk and subsequent usefulness in management zone creation? Third, can the two aforementioned issues be resolved in a manner which will result in a method that is easily adaptable for producers and will provide them with cost savings?

The issue of the size of the spatial scale upon which to separate recommendations includes two major considerations. *R. reniformis* is known to have geographical variation with respect to reproduction, pathogenicity, morphometrics, temperature effects on embryogenesis, and genetics (Agudelo *et al.*, 2001; Agudelo *et al.*, 2005; Arias *et al*., 2009; Leach *et al.*, 2009; McGawley *et al.*, 2010), some of which vary within a single state. A second consideration is the diversity of soils within regions and states. For example, Alabama has six major soil areas where cotton is produced, each with quite different characteristics and levels of in-field variability. It is also well known that certain soils, such as those found in the Mississippi River Delta region, support far greater populations of *R. reniformis* in comparison to the soils found in the Coastal Plain region of the Southeast, yet the amount of yield loss in each region is similar.

The second issue is which parameters provide the best indicators of economic risk and subsequent usefulness in management zone creation? As was detailed earlier, soil texture distribution has been studied quite extensively in relation to predicting which location in a field is more favorable to *R. reniformis* reproduction. While this technique has been used successfully for other species of plant-parasitic nematodes, the success of *R. reniformis* to reproduce and cause damage in a wide variety of soil textural distributions renders this method much less useful. Economic threshold level of *R. reniformis* is another parameter to be considered. Potential soil productivity has been shown to affect this relationship (Moore *et al.*, 2011a) as well as the possibilities of additional stress due to the lack of water throughout the growing season (Moore *et al.*, 2011c). The use of yield maps from previous years, if they exist, is another strong possibility for guidance of zone creation. Massey *et al.* (2008) determined that utilizing yield maps to assess profitability of corn, soybean, and grain sorghum based on field features and input costs could provide producers with information to assess management options.

Can SSM for *R. reniformis* on cotton become an easily adaptable and cost-saving tool for cotton producers? The answer depends on two major issues; spatial scale and zone creation parameters. Spatial scale and zone creation parameters are currently a focal point of research throughout areas affected by *R. reniformis*. Furthermore, many of the techniques for site-specific management are used for a variety of other issues and could be easily adapted with the correct guidelines. The identification of parameters to quantify economic risk and the understanding of how these parameters will differ over geographical areas will determine if SSM can enable cotton producers to gain an economic advantage over *R. reniformis*.

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