[2] Department of Entomology and Plant Pathology, Box 9655, Mississippi State University, Mississippi State, MS 39762
[3] University of Florida, 30 Research Road, Quincy, FL 32351
[4] Southern States Cooperative, Inc., 2552 Chula Brookfield Rd., Tifton, GA 31794
United States of America

EVALUATION OF VARIABLE RATE NEMATICIDE APPLICATIONS USING PRECISION FARMING METHODS TO MANAGE *MELOIDOGYNE INCOGNITA* ON COTTON[1]

by

R. E. BAIRD[2], J. R. RICH[3], and D. WATERS[4]

Summary. Three field trials were conducted on a farm in southwest Georgia, U.S.A., comparing standard single rate to variable rate applications of 1,3-dichloroproprene (1,3-D) and aldicarb on the growth of cotton and soil population densities of *Meloidogyne incognita*. A 40 ha field was subdivided into 0.4 ha grid areas by using a global positioning system (GPS). Soil samples for nematode analyses were obtained from each grid area, and maps depicting the range of *M. incognita* second stage juvenile (J2) population densities were created. Variable rates of 1,3-D and aldicarb were applied using prototype equipment designed to enable site specific applications based on nematode densities which varied among the field plots. During the two growing seasons, plant stands and *M. incognita* J2 population densities generally did not differ among the treatments. The variable rate aldicarb applications did not show yield or economic advantages over the use of standard single rate applications of this nematicide. Variable rate applications of 1,3-D, however, produced either similar or significantly greater yields than the single uniform rate applications. The cost of soil sampling and analysis needed with variable rate application of 1,3-D was offset by the savings obtained from reduced total chemical usage in both years. The lower chemical input costs and environmental benefits of variable rate 1,3-D application can be recommended for *M. incognita* control on Georgia cotton farms.

Management of plant parasitic nematodes has become an increasingly important aspect of cotton production in the United States. Surveys of the U.S. cotton industry in 1997 estimated that 3.7% of the crop yield (762,520 bales) was lost due to nematodes (Blasingame, 1998). In Georgia, a statewide survey in 1999 showed cotton loss due to nematodes was 8% (Baird *et al.*, 1998). Southern root-knot (*Meloidogyne incognita*), Columbia lance (*Hoplolaimus columbus*), reniform (*Rotylenchulus reniformis*), and sting (*Belonolaimus longicaudatus*) were the most common nematode species identified in cotton fields. The southern root-knot nematode was the most abundant species and was detected in 81% of the 104 cotton producing counties.

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Nematicide application is becoming the standard practice for controlling cotton nematodes in Georgia. Aldicarb and 1,3-D are the most efficacious nematicides used by producers in the southeastern United States (Schmitt and Bailey, 1990). In Georgia, 1,3-D and soil treatments with a combination of aldicarb similarly increased cotton yield in *R. reniformis* and *M. incognita* infested fields (Baird *et al.*, 2000 a, b). Aldicarb is more frequently applied and used at subnematicidal rates to control thrips (*Frankliniella* spp.) in Georgia cotton fields. Numerous studies have been conducted evaluating aldicarb at various rates for control of major nematode pests of cotton (Gazaway and Rush, 1995; Baird and McDaniel 1996; Kinloch and Rich, 1998). When the aldicarb was applied at 0.6, 0.8 and 1.2 kg a.i./ha, the greatest yields were usually obtained at the two higher rates.

Damage to cotton from *M. incognita* infestations is generally patchy or variable within a field (Baird *et al.*, 1996), and the current practice of whole field nematicide treatment may not be economically justified. Applying nematicides only to specific sites within a field where the nematode population densities exceeds threshold levels could be a viable option for lowering costs and maximizing profits. Patchy distribution of pests in a field, including nematodes, is common, and precision agricultural technologies are being developed to target only those areas in a field that have threshold populations (Robert *et al.*, 1993). Consequently, much research is being devoted to determine spatial distribution of pests and the feasibility of site-specific management techniques. To date, only a few reports of site-specific management of pests have been made such as those on Colorado potato beetle (Weisz *et al.*, 1995) and Texas panicum (Green *et al.*, 1997). Reliable mapping of pests may require intensive sampling techniques which may prove to be cost prohibitive. It is important to determine if site specific nematicide rates can be reduced to compensate for the expenses of soil sampling and analysis. Three experiments were conducted to compare standard single rate applications with variable-rate applications of aldicarb and 1,3-D to manage *M. incognita* (Kofoid *et* White) Chitw. in cotton using precision farming techniques.

Materials and methods

Experiments were conducted at the Shiraland Plantation near the town of Hopeful in southwest Georgia on a loamy sand soil (Loamy, kaolinitic, thermic, Arenic Kandiudults; pH 6.0-6.2). Two trials were established in 1998 (trials 1 and 2) and one trial in 1999. All trials were located within the same field, but in different quadrants of the same center pivot irrigation area. Cotton was planted using strip-tillage, and management of the crop followed University of Georgia recommendations for production in irrigated cotton fields (Brown *et al.*, 1997). Intensive soil sampling (20 x 20 m grids) was conducted in the 40 ha field in November 1997 and Novembre 1998 to determine nematode population densities. In each grid, ten soil cores were taken to a depth of 20 cm, and the nematodes extracted from a 100 cm^3 subsample using a centrifugation flotation (Jenkins, 1964). A point taken from the center of each grid was georeferenced using Satloc GPS (Scottsdale, AZ). A map depicting the range in nematode population densities was created usign AgLink Professional (AGRIS, Roswell, Georgia), a Geographic Information System (GIS) software package (Figure 1). For treatment evaluation purposes, each test area was subdivided into 6 row plots which varied in length from 457 to 518 m in 1998 and from 421 to 616 m in 1999. The nematicide regimes were either standard single rate or variable rate applications. Nematicide rates were based on the mean population densities from the 0.4 ha subplots within an individual strip. Current University of Georgia nematode threshold levels were used to help in determining application rates of aldicarb and 1,3-D, and adjusted based on the presence of different soil types (Brown *et al.*, 1997).

Fig. 1 - *Meloidogyne incognita* population levels (J2/100 cm^3) determined from samples taken in 0.4 ha grids in November 1997 (Pivot 1A) and November 1998 (Pivot 1B). Computer program AgLink Professional for Windows™ was used to develop the nematode density zones within each quadrant. Strip plots were established (not shown) within each quadrant comparing variable and conventional application rates of aldicarb and 1,3-dichloropropene.

Aldicarb and 1,3-D were applied at planting in all three experiments. On 29 April 1998 (trials 1 and 2) and 2 May 1999, plots were established in a randomized complete block design with five replicates per treatment. Cotton (*Gossypium hirsutum* L.) cv. Paymaster 1220 B/RR was planted in 0.91 m wide centers at a rate of 12-15 seed/m of row. Variable rates of aldicarb were applied with hopper box planters driven by a 12 Volt electric motor (Rae Corp., McHenry, IL), and controlled by the variable rate application software Fieldlink (AGRIS), a rate controller (Mid-Tech TASC-6500, Midwest Technologies, Inc., Roswell, Georgia), and Satloc GPS. Standard and variable rate applications of 1,3-D were injected using single in-row chisels at 30 cm below final planting depth and the chisel opening was sealed with a press wheel. Variable rate 1,3-D was applied with the same electric motor system used for aldicarb application, but was attached to a prototype pumping system (Chemical Container Corporation, Lakeland, FL) which enabled 1,3-D to be applied at different rates. The variable rate treatments, based on nematode density from the previous autumn sampling are presented in Table I. Plant stands from each plot were obtained from two 15.2 m rows on 2 and 7 June in 1998 and 1999, respectively. Nematode samples were taken on 10 July 1998 and 5 July 1999. Plots were mechanically harvested on 15 September 1998 and 10 October 1999. Lint yields were determined by multiplying seed cotton yields by a factor of 0.35.

TABLE I - *Variable rates in a.i./ha and application methods of aldicarb and 1,3-dichloropropene (1,3-D) used in three field trials as determined by initial* Meloidogyne incognita *juvenile (RK) threshold levels per 100 cm^3 soil.*

Refer to Table II for the following two treatments tested:

Aldicarb variable in-furrow (IF):
0.6 kg in-furrow (IF) (≤ 25 - RK); 0.9 kg (IF) (26-70 RK); 1.2 kg (IF) (71-124 RK).

Aldicarb variable sidedress (SD):
0.6 kg (IF) (≤ 25 RK); 0.6 kg (IF) + 0.6 kg (SD) (26-70 RK); 0.6 kg (IF) + 0.9 kg (SD) (71-124 RK); and 0.9 kg (IF) + 0.9 kg (SD) (≥ 125 RK).

Refer to Table III for the following three treatments tested:

1,3-dichloropropene (1,3-D) variable rate:
Aldicarb applied 0.6 kg (IF) to all plot rows; 1,3-D applied at 16 kg in-row (IR) (25-70 RK); 32 kg (IR) (71-199 RK); and 48 kg (IR) (≥ 200 RK).

Aldicarb variable in-furrow (IF):
Aldicarb applied at 0.6 kg (IF) to all plot rows; 0.9 kg (IF) (26-70 RK); 1.2 kg (IF) (71-124 RK); and 0.9 kg (IF) + 0.9 kg (SD) (≥ 125 RK).

Aldicarb variable sidedress (SD):
Aldicarb applied at 0.6 kg (IF) to all plot rows; 0.6 kg (IF) + 0.6 kg (SD) (26-70 RK); 0.6 kg (IF) + 0.9 kg (SD) (71 - 124 RK); and 0.9 kg (IF) + 0.9 kg (SD) (≥ 125 RK).

Refer to Table IV for the following three treatments tested:

Aldicarb variable sidedress (SD):
Aldicarb applied at 0.6 kg (IF) (≤ 25 RK); 0.9 kg (IF) (26-70 RK); 1.2 kg (IF) (71-124 RK); and 0.9 kg (IF) + 0.9 kg (SD) (≥ 125 RK).

Aldicarb variable in-furrow (IF):
Aldicarb applied at 0.9 kg (IF) to all plot rows; 0.6 kg (SD) (76-124 RK); and 0.9 kg (SD) (≥ 125 RK).

1,3 - dichloropropene variable rates:
Aldicarb applied at 0.6 kg (IF) to all plot rows; 1,3-D applied at 16 kg (IR) (26-75 RK); 32 kg (IR) (76-199 RK); and 48 kg (IR) (≥ 200 RK).

Economic data was based on the 1999 average U.S. dollar price of $ 1.44/kg cotton lint. Aldicarb cost was $ 45.59/kg a.i. and 1,3-D cost was $ 2.39/kg a.i. Soil collection and analysis costs were estimated to be $ 25.00/ha using 0.4 ha grids. This cost was estimated by Southern States Cooperative, Inc., Precision Farming Division, Tifton, Georgia.

Results

In 1998, plant stands and mid season nematode population densities were not different (P ≤0.05) among treatments at field trial 1 (Table II). The variable rate aldicarb in-furrow treatment produced yields similar to the aldicarb control treatment (0.6 kg a.i./ha). Yields of the variable rate sidedress treatment of aldicarb and the 0.9 kg a.i./ha single rate treatment were significantly greater (P ≤0.05) than the single rate aldicarb treatment (0.6 kg a.i./ha). Chemical costs for the variable-rate in-furrow and sidedress treatments were similar to or greater than the single rate aldicarb control application of 0.6 kg a.i./ha. The additional increased input costs associated with soil sampling and nematode assays for the variable rate treatments further lowered the total economic return compared to the single rate applications.

Plant stands and mid-season nematode population densities were not different (P ≤0.05) among treatments in the field trial 2 in 1998 (Table III). All treatments containing 1,3-D produced greater yields than the control with aldicarb. After sampling and chemical costs were included, total economic return was greatest with the variable rate 1,3-D treatment compared to all other treatments. Use of variable rate application of 1,3-D resulted in a substantial reduction in fumigant applied to the soil compared to the single rates. The aldicarb variable rate sidedress treatment had higher yield and economic return than the single rate aldicarb control treatment applied at 0.6 kg a.i./ha.

In 1999, plant stands and mid season nematode population densities were similar among treatments (Table IV). Yield in the plots containing the standard single rate application of aldicarb (0.6 kg a.i./ha) was numerically lower than for all other aldicarb treatments. All treatments containing 1,3-D had greater yields (P

TABLE II - *Comparison of single rate and variable rate applications of aldicarb to manage* M. incognita *on cotton in field trial 1, 1998.*

Treatment[a]	Rate a.i./ha	Plant stand	Juveniles/ 100 cm^3	Lint (kg/ha)	Chemical $ cost/ha	Return[b] in $ /ha
aldicarb (control)	0.6 kg (IF)[c]	63.5 a[d]	57.2 a	732.4 b	12.15	1042.5
aldicarb	variable (IF)	77.1 a	77.9 a	754.0 ab	17.18	1043.6
aldicarb	0.9 kg (IF)	71.7 a	47.3 a	788.3 a	17.36	1117.8
aldicarb	variable (SD)	67.4 a	72.9 a	796.3 a	19.75	1101.9

[a] Refer to Table I for a detailed description of the treatments and rates for variable rate aldicarb applications.
[b] Yield was valued at $ 1.44 U.S. dollars/kg lint; chemical $ costs/ha and the variable rate nematode sampling and assay cost $25.00/ha were subtracted from $ return/ha.
[c] IF indicates aldicarb application in-furrow at planting; SD indicates aldicarb is applied as a sidedress.
[d] Means followed by the same letters within a column are not significantly different (P ≤ 0.05) according to Waller-Duncan k-ratio t-test.

TABLE III - *Comparison of single rate and variable rate applications of aldicarb and 1,3-dichloropropene (1,3-D) to manage* M. incognita *on cotton in field trial 2, 1998.*

Treatment[a]	Rate a.i./ha	Plant stand	Juveniles/ 100 cm^3	Lint (kg/ha)	Chemical $ cost/ha	Return in $ /ha[b]
1,3-D + aldicarb	32 kg (IR)[c] 0.6 kg (IF)	50.0 a[d]	87.6 a	779.2 a	41.75	1080.3
1,3-D + aldicarb	variable (IR) 0.6 kg (IF)	51.7 a	48.3 a	810.7 a	21.53	1120.9
aldicarb	variable (IF)	51.5 a	143.2 a	743.7 ab	21.00	1028.6
aldicarb	0.6 kg (IF)	51.9 a	73.4 a	667.6 b	17.36	944.0
aldicarb	variable (SD)	52.0 a	103.3 a	775.0 a	32.09	1058.9

[a] Refer to Table I for a detailed description of the treatments and rates for the variable rate nematicide applications.
[b] Yield was valued at $ 1.44 U.S. dollars/kg lint; chemical $ costs/ha and the variable rate nematode sampling and assay cost $ 25.00/ha was subtracted from $ return.
[c] (IF) indicates aldicarb application in-furrow at planting; (SD) is sidedress aldicarb application with a previous in-furrow treatment; (IR) indicates 1,3-D chisel-injected in-row prior to planting plus an aldicarb (0.6 kg a.i./ha) thrips rate at planting.
[d] Means followed by the same letters within a column are not significantly different ($P \leq 0.05$) according to Waller-Duncan k-ratio t-test.

TABLE IV - *Comparison of single rate and variable rate applications of aldicarb and 1,3-dichloropropene (1,3-D) to manage* M. incognita *on cotton in a field trial, 1999.*

Treatment[a]	Rate a.i./ha	Plant stand	Juveniles/ 100 cm^3	Lint (kg/ha)	Chemical $ cost/ha	Return in $ /ha[b]
aldicarb (control)	0.6 kg (IF)	63.1 a[c]	156.0 a	542.0 d	12.15	768.3
aldicarb	variable (IF)	66.2 a	133.2 a	603.9 b-d	19.79	824.8
aldicarb + aldicarb	0.9 kg (IF) + 0.9 kg (SD)	72.5 a	201.6 a	638. bc	34.72	884.0
aldicarb	0.9 kg (IF)	76.2 a	155.4 a	598.9 b-d	17.36	845.1
aldicarb	variable (IF)	60.6 a	207.1 a	563.0 cd	20.17	765.6
1,3-D + aldicarb	32 kg (IR) 0.6 kg (IF)	65.3 a	98.3 a	660.0 ab	41.75	908.7
1,3-D + aldicarb	16 kg (IR) + 0.6 kg (IF)	64.3 a	117.2 a	621.9 b-d	29.51	866.0
1,3-D + aldicarb	48 kg (IR) + 0.6 kg (IF)	71.5 a	101.2 a	759.9 a	64.12	1030.1
1,3-D + aldicarb	variable (IR) 0.6 kg (IF)	65.2 a	125.8 a	668.9 ab	26.04	912.2

[a] Refer to Table I for a detailed description of the treatments and rates for the variable rate nematicide applications.
[b] (IF) indicates aldicarb application in-furrow; (SD) is sidress aldicarb application with a previous at planting treatment; (IR) is 1,3-D chisel injected in-row with an thrips rate of aldicarb (0.6 kg a.i./ha) at planting.
[c] Means followed by the same letters within a column are not significantly different ($P \leq 0.05$) according to Waller-Duncan k-ratio t-test.

≤0.05) than the 0.6 kg a.i./ha single rate aldicarb treatment, except in plots where the low rate of 1,3-D (16 kg a.i./ha) was applied. The variable rate application of 1,3-D did not produce a higher yield than standard rate 1,3-D treatment (32 kg a.i./ha). Except for the highest rate of 1,3-D, yields in the variable rate and standard rate were similar, but the amount of product applied was substantially reduced by use of variable rate applications.

Discussion

During the study period, variable rate aldicarb applications did not show an economic advantage over the single rate control applications of 0.6 kg a.i./ha. Economic return using variable rate applications of aldicarb was lower than the existing standard application. These results support a previous study conducted in Texas with aldicarb for control of *M. incognita* in which variable rate applications were not economical when compared to the single rate standard applications (Wheeler *et al.*, 1999). Sidedress application of aldicarb is still in the developmental stage and additional studies on application timing for both single or variable rates are needed.

Comparisons of results for specific nematicide treatments often vary between growing season (Wheeler *et al.*, 1999). Specific site and environmental factors have been reported to influence results including amount of available soil moisture, presence of alternate hosts (e.g. weeds), and nematode population densities present within each study site. Variations in nematode population densities within plots, and between sampling dates, make it difficult to evaluate direct effects of nematicides on nematode populations (Noe, 1990). Efficacy of aldicarb is particularly influenced by the available moisture present in fields which prevents effective distribution of the chemical (Hough *et al.*, 1975). Additionally, since conventional studies using single rates of aldicarb are often inconsistent among different years, trying to determine the importance of variable rate becomes even more difficult. Further studies over several years may be necessary to determine the potential of variable rate aldicarb usage in cotton nematode management.

The variable rate application of 1,3-D produced yields similar to or greater (P ≤0.05) than the single rate treatment. In both years the additional input costs using variable rate technology was offset by the savings obtained from the reduced total amount of 1,3-D applied. In previous studies, 1,3-D applied at 16 kg a.i./ha did not give consistent and adequate control for above threshold level populations of *M. incognita* (Baird, unpublished data; Kinloch and Rich, 1998). In this study, 1,3-D at 48 kg a.i./ha single rate treatment had the greatest yield and total return compared to all other treatments. These data are similar to those of Kinloch and Rich (1998), who found increased yields as rates of 1,3-D were increased from 0.64 kg a.i./ha in a *M. incognita* infested cotton field. The variable rate 1,3-D treatments had similar mean yields compared to the standard single rate treatment of 31 kg a.i./ha, but with the reduced chemical input cost for control, the variable rate treatment produced greater total economic return than the former treatment.

In conclusion, data from these tests show that variable rate nematicide applications are feasible and can lessen the amount of chemical applied for nematode management. Reduced levels of nematicides are environmentally safer as well as more profitable to growers if 1,3-D is used compared with conventional applications throughout a field.

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