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YIELD OF CROPS TREATED WITH 1-TRIACONTANOL

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YIELD OF CROPS TREATED WITH 1-TRIACONTANOL

By

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ABSTRACT

YIELD OF CROPS TREATED WITH 1-TRIACONTANOL

By

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The growth and yield of several vegetable and field crops were sometimes increased by applications of 1-triacontanol (TRIA) in 1977 and 1978. Increased yields from TRIA applications were obtained over a wide range of rates. A single application of TRIA was as effective as multiple applications. There was no apparent optimum growth stage for application. The response of carrot (Daucus carota) and sweet corn (Zea mays) to TRIA was greatest when grown under lower nitrogen regimes. Soaking seed of crops in dichloromethane containing TRIA did not prove to be an effective method of application for crops directly seeded in the field. However, it was found effective for tomatoes (Lycopersicon esculentum) grown in the greenhouse and transplanted to the field. Granular formulations of TRIA, placed on the soil surface, increased the yield of wheat (Triticum aestivum), tomato and asparagus (Asparagus officinalis). The granular formulation of TRIA, placed with the seed, was found to decrease the yield of cucumbers (Cucumis sativus).

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I wish to thank Dr. Stanley Ries for his aid in my research and Drs. Alan Putnam, William Meggitt, Everett Everson and Hugh Price for their guidance and assistance. I would like to acknowledge the cooperation of the farmers and county agents of Michigan, particularly Gregory Varner and Edgar Strong, for their willingness to provide their assistance, without which many of these studies would not have been possible. I also wish to express my appreciation to David Glenn and other friends, for their support throughout these studies, particularly Dr. Jennifer Jones for her assistance in writing this thesis.

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INTRODUCTION

Triacontanol (TRIA), a constituent of leaf wax among plant species (5,6,7,12), has been shown to increase the dry weight of several crops (11). Greenhouse studies demonstrated that TRIA, applied to the seed, soil or foliage improved the growth of several crops (9). The objective of this research was to determine if TRIA could be developed as an effective growth regulator for increasing crop yield. These field studies were initiated to determined the optimum rate, number of applications, optimum time and best method of applying TRIA to increase crop yield.

LITERATURE REVIEW

Coarsely chopped alfalfa (Medicago sativa) hay increased plant growth and yield when placed in a band below and to the side of crop seeds or seedlings (8). A crystalline substance, isolated from alfalfa meal, was identified as 1-triacontanol [$CH_3(CH_2)_{28}CH_2OH$] by mass spectrometry and was shown to increase the dry weight and water uptake of rice (Oryza sativa) seedlings grown in nutrient culture (11). It was also shown that foliar sprays increased the growth of barley (Hordeum vulgare), corn and tomato grown in soil. The response of rice and tomatoes to synthetic and natural triacontanol was similar. Triacontanol was first identified in 1933 as the principle long-chain alcohol component of wax derived from alfalfa leaves (2). TRIA occurs in different quantities in the wax of many plant species and is present throughout the environment (5,7,12). TRIA was found to be present in the inner tissue of several plant species suggesting a role aside from cuticular functions (6). TRIA increased the dry weight and leaf area of rice seedlings grown in nutrient culture at 2.3×10^{-8} M (10 µg/l) within 3 hours in the light or dark (10). TRIA also increased Kjeldahl-N content up to 30% after 6 hours in the dark. The dark response is sensitive to atmospheric CO_2 and O_2 concentration (1). Treated rice seedlings increased dry weight in the dark in the presence of 200 to 400 ppm atmospheric CO_2 and 5% O_2. The treated seedlings did not fix more atmospheric CO_2 in the dark. TRIA increased the protein content

and growth *in vitro* of cell cultures of haploid tobacco (*Nicotiana tabacum*) (3). The increase in growth was due to an increase in cell numbers. Octocosanol [$CH_3(CH_2)_{26}CH_2OH$], the 28-C analog did not increase the growth of tobacco cell cultures (3) or the growth of rice seedlings (10). Octocosanol inhibited the response to TRIA at 2.3×10^{-8} M in rice seedlings at concentrations as low as 2.4×10^{-12} M (4). Primary alcohols with carbon chain lengths of 16, 18, 22 and 24 also inhibited the TRIA response in rice seedlings indicating that chain length, presence and position of hydroxyl group may be specific for the growth promoting activity of TRIA. The growth of several vegetable and field crops in the greenhouse was increased by applications of TRIA to the foliage, soil or seed (9). The dry weight increase occurred at application rates as low as 0.01 mg/l and was maintained over a 1000-fold range in concentration.

Clearly, the efficacy of TRIA has been demonstrated as a compound capable of increasing the growth of many crops in greenhouse and laboratory situations. There have been no reports of TRIA increasing yield of crops in the field previous to the initiation of this study.

MATERIALS AND METHODS

Formulations and Methods of Application

TRIA was applied in the field studies as a seed treatment, foliage spray or a soil treatment. TRIA was applied using formulations supplied by the American Cyanamid Company, Princeton, New Jersey. Foliar applications were prepared from a 2.5% or 0.01% concentrated emulsion. Due to the small amount of the emulsion required for applying the low rates of TRIA, Tween 20 at 0.1% by volume was utilized as a surfactant in all foliar studies. Controls consisted of Tween 20 or emulsion blank in all studies. All foliar treatments were applied with one or two flat fan nozzles at rates of 423 l/ha to 984 l/ha in 1977. In 1978, foliar treatments were applied with one flat fan nozzle or 2 even spray nozzles at rates from 225 l/ha to 438 l/ha. Seed treatments in both years consisted of soaking the seed in dichloromethane (DCM) containing TRIA (0.01 to 10 mg/l) for one hour. Controls consisted of seed soaked in DCM for 1 hour and untreated seed. The seeds were dried at room temperature prior to planting. In studies involving granular applications of TRIA, formulations of 2.5×10^{-4}%, 1.0×10^{-3}%, 4.0×10^{-3}% and a granular blank were utilized.

Seed Treatment

Seed of several crop species; carrot, sweet corn, cucumber, lettuce (Latuca sativa) and radish (Rhaphanus sativus) were soaked in DCM

containing TRIA (Table 1). The crops were planted in East Lansing using a V-belt planter. Crops were irrigated frequently to prevent wind erosion until established. Weeds were controlled by hand cultivation.

In experiments comparing alfalfa hay and TRIA applications on the yield of barley, sweet corn and tomato, the seed were soaked in DCM prior to sowing or were sown with finely ground alfalfa hay (Table 2). Crops were planted on a Spinks sandy loam soil. All treatments received 1.0 g finely sifted vermiculite to hold the alfalfa hay on the planter. Weeds were controlled by hand cultivation.

In 1978, 'Heinz 1350' tomato was the only crop studied using the method of soaking seed in DCM containing TRIA (Table 3). Transplants from control and treated seed were grown in plastic flats (26 x 53 cm) containing vermiculite. The flats were placed in a growth chamber with a day-night regime of 16 hours (25°C) and 8 hours (20°C). After 15 days, seedlings were transplanted into wooden flats (35.5 x 51 cm) containing a greenhouse soil composed of sand, peat and loam (1:1:1) and placed in a greenhouse with the night temperature maintained at approximately 27°C. The plants received 0.5 l of a water soluble 20-20-20 fertilizer twice a week (1 g/l). Forty-two day-old plants were sorted by size for blocks and placed in a growth chamber for the night (16°C). The plants were transplanted with a commercial transplanter. Additional TRIA treatments were applied as a foliage spray (50 and 500 mg/ha) or a granular topdressing (0.4, 1.6 and 6.4 kg/ha) in 12.7 cm bands on each side of the row.

Granular formulations of TRIA were placed with the seed of 'Green Star' pickling cucumbers on a Spinks sandy loam soil in East Lansing in 1978. The crop was planted June 6 with a V-belt planter to a depth

Table 1. Cultural conditions for crops soaked in DCM containing TRIA in East Lansing, in 1977.

	Crop and Cultivar				
	cucumber 'Premier'	carrot 'Spartan Classic'	lettuce 'Buttercrunch'	radish 'Cherry Bell'	sweet corn 'Gold Cup'
Soil type	Spinks sandy loam	Spinks sandy loam	Spinks sandy loam	Spinks sandy loam	Miami loam
Treatment date	6/18	4/13	4/13	5/16	5/12
Planting date	6/19	4/14	4/14	5/18	5/13
Harvest date	7/26	7/6	6/17	6/10	8/3
Type of harvest	multiple	single	single	single	multiple
Plot size (m)	0.9x7.6	0.6x7.6	0.6x7.6	0.6x7.6	0.9x7.6
Depth (cm)	3.2	2.0	1.3	1.3	3.8
Fert applied	400 kg/ha 12-12-12	400 kg/ha 12-12-12	400 kg/ha 12-12-12	400 kg/ha 12-12-12	560 kg/ha 12-12-12

Table 2. Cultural conditions for alfalfa-triacontanol comparison studies in East Lansing in 1977.

	Crop and Cultivar		
	barley 'Larker'	sweet corn 'Gold Cup'	tomato 'Heinz 1350'
Treatment date	4/28	5/16	5/17
Planting date	5/2	5/20	5/20
Harvest date	7/21	8/9	8/30
Type of harvest	single	multiple	multiple
Plot size (m)	0.3x7.6	0.9x7.6	1.5x7.6
Planting method	V-belt	V-belt	V-belt
Depth (cm)	2.5	3.8	2.0
Fert applied	560 kg/ha 12-12-12	560 kg/ha 12-12-12 plus 144 kg N/ha on 6/14	560 kg/ha 12-12-12 plus 438 kg/ ha 10-20-12 on 7/11

Table 3. Cultural conditions of 'Heinz 1350' tomato soaked in DCM containing TRIA in 1978.

	Location	
	East Lansing	Clarksville
Soil type	Spinks sandy loam	Drysden sandy loam
Treatment date	4/11	4/11 and 6/19
Planting date	5/17,5/31,6/19,7/3 and 7/18	4/12
Transplanting date	--	5/25
Harvest date	9/5 and 9/11 for 5/17 seeding	8/24 through 9/6
Type of harvest	multiple	multiple
Plot size (m)	1.2x3.0	1.5x9.1
Depth (cm)	1.3	1st leaf node
Fert applied	589 kg/ha 5-20-20	604 kg/ha 10-20-20
Weed control	diphenamid (5.6 kg a.i./ha)	diphenamid (5.6 kg a.i./ha) metribuzin (0.3 kg a.i./ha)

of 3.2 cm. Weeds were controlled with a combination of bensulide (4.5 kg a.i./ha) and naptalam (3.4 kg a.i./ha) applied at planting and incorporated with irrigation. Plot size was 0.7 x 7.5 m; plots were thinned to a uniform number of plots per block 9 days after emergence. A simulated mechanical harvest was made when the plants were 48 days old.

Foliar Treatments

Treatments were applied to several crop species in 1977 and 1978 to study the effect of rate, number, time and fertility level on the crops response to TRIA.

In 1977 and 1978, rate tests were conducted involving cucumber, lettuce, radish, sweet corn and tomato crops (Table 4). The cucumber test was located in Gratiot County. Prices used to calculate cucumber values were $11.00, 6.30, 3.30, .50 and 1.20 for grades 1, 2, 3, oversize and nubs, respectively. All other crops were located in the East Lansing vicinity.

Plots of cucumber, navy bean (Phaseolus vulgaris) and tomato were treated with TRIA once or at a number of intervals throughout the growing season (Table 5). The crops were grown at two locations, Gratiot County and East Lansing, on three soils. 'Premier' cucumbers were

crops of radish and lettuce. Prices used to calculate the values of the cucumber yields were #3.67 and $1.50/cwt for grades 1-3 and grade 4, respectively. In all tests, except for tomatoes, two guard rows were placed between each treated plot to minimize the possibility of chemical drift.

Table 4. Cultural conditions for crops receiving foliar applications of TRIA in 1977 and 1978 in Central Michigan.

	Crop and Cultivar			
	cucumber 'Green Star'	lettuce 'Buttercrunch'	radish 'Cherry Bell'	sweet corn 'Gold Cup'
Year	1978	1977	1977	1977
Soil type	Parkhill clay loam	Spinks sandy loam	Spinks sandy loam	Miami loam
Planting date	6/10	4/14	4/15	5/25
Planting method	commercial drill	V-belt	V-belt	V-belt
Treatment date	6/28	5/18 and 5/25	5/3 and 5/11	6/16
Stage of crop	2nd leaf	2nd-3rd leaf	2nd leaf	2nd-3rd leaf
Harvest date	8/4	6/17	5/16	8/15
Type of harvest	single	single	single	multiple
Plot size (m)	0.76x15.2	0.6x7.6	0.6x7.6	0.9x7.6
Nozzle size	1-8003	1-8004	1-8004	1-8004
l/ha delivered	429	984	984	644

Table 4 (continued)

	Crop and Cultivar			
	cucumber 'Green Star'	lettuce 'Buttercrunch'	radish 'Cherry Bell'	sweet corn 'Gold Cup'
Fert applied	329 kg/ha 12-12-12	560 kg/ha 12-12-12	560 kg/ha 12-12-12	560 kg/ha 12-12-12 plus 144 kg N/ha on 6/4
Weed control	chloramben methylester	hand-hoeing	hand-hoeing	atrazine (1.2 kg a.i./ha)

Table 5. Cultural conditions for crops receiving foliar sprays of TRIA at multiple intervals in 1977.

	Crop and Cultivar			
	cucumber 'Green Star'	cucumber 'Premier'	dry bean 'Sanilac'	tomato 'Heinz 1350'
Soil type	Parkhill clay loam	Spinks sandy loam	Parkhill clay loam	Miami loam
Planting date	6/10	7/13	6/5	5/23
Treatment date	6/28	7/27	6/14	6/16
Stage of crop	2nd leaf	2nd leaf	1st trifoliate	1st flowering
Harvest date	8/1	8/30	9/27	8/16
Type of harvest	single	multiple	single	multiple
Plot size (m)	0.7x15.2	0.9x7.6	0.8x15.2	1.5x7.6
l/ha	423	423	423	423
Fert applied	448 kg/ha 12-12-12	438 kg/ha 12-12-12	279 kg/ha 12-12-12	504 and 1008 kg/ha 12-12-12
Weed control	chloramben and naptalam	hand-hoeing	trifluralin and EPTC	diphenamid (5.6 kg a.i./ ha)

Navy bean, tomato, and wheat plots were tested in 1978 in an attempt to determine the optimum morphological stage of growth with respect to TRIA applications (Tables 6 and 7). In the wheat and navy bean tests, two guard rows were placed between each treated plot to avoid spray drift. The wheat plots were harvested with a small plot combine.

Nitrogen studies were conducted in both years in East Lansing on a Spinks sandy loam soil (Table 8).

Soil Treatments

Soil applications of TRIA consisted of water drenches and of granular formulations applied around the plants (Tables 9 and 10).

Statistical Methods

Factorial experiments were utilized in most field studies with rate, number and morphological stage at TRIA applications as variables. Randomized complete block designs were used with the exception of the studies on nutrient levels, age of application and method of application. In these studies, a split-plot design was utilized with nitrogen, age of crop and placement of chemical as the main-plot and TRIA treatments as the sub-plots.

All field studies consisted of 4-6 blocks.

The results of all tests were subjected to analysis of variance and relevant orthogonal and non-orthogonal comparisons were made.

Table 6. Cultural conditions of wheat treated with foliage sprays in Central Michigan in 1978.

	Location			
	East Lansing		Saranac	
Soil type	Conover loam		Matherton loam	
Cultivar	'Ionia'	'Yorkstar'	'Ionia'	'Yorkstar'
Stage of crop and date				
Early tiller	4/27	4/27	4/27	4/27
Boot	6/2	6/2	6/3	6/3
Post anthesis	6/27	6/27	6/28	6/28
l/ha	225	225	225	225
Plot size (m)	1.2x4.9	1.2x4.9	1.2x4.9	1.2x4.9
Harvest data	8/1	8/1	7/28	7/28

Table 7. Cultural conditions of tomato and dry bean crops receiving foliar sprays at various stages of growth in 1978.

	Crop and Cultivar	
	navy bean 'Sanilac'	tomato 'Heinz 1350'
Soil type	Parkhill clay loam	Spinks sandy loam
Planting date	6/10	5/30
Planting method	commercial planter	V-belt
Plot size (m)	0.76x15.2	1.5x7.6
l/ha	438	438
Fert applied	336 kg/ha 12-12-12	589 kg/ha 12-12-12
Weed control	chloramben and trifluralin	metribuzin (0.3 kg a.i./ha)
Harvest date(s)	9/20	9/29 and 10/10
Type of harvest	single	multiple
Morphological stage	1st trifoliate 1st pod set	1-3 leaves 1st flower
Treatment date(s)	7/7 and 8/8	6/28 and 7/18

Table 8. Cultural conditions of carrots and sweet corn grown on different nitrogen levels.

	Crop	
	Carrot 'Spartan Classic'	Sweet Corn 'Gold Cup'
Year	1977	1978
Planting date	4/14	5/26
Depth of seed (cm)	2	3.8
Planting method	V-belt	V-belt
Treatment date	5/18	6/14
l/ha	984	438
Nozzle size	1-8004	1-8003
Harvest date	7/6	8/18
Type of harvest	single	multiple
Weed control	hoeing	atrazine 1.1 kg a.i./ha + alachlor 2.2 kg a.i./ha
Initial fertility	560 kg/ha 12-12-12	560 kg/ha 5-20-20
Additional N (ammonium nitrate)	67 kg N/ha	84 kg N/ha, 168 kg N/ha

Table 9. Cultural conditions of several crops receiving TRIA applications to the soil around the plants in 1977 and 1978.

	Crop and Cultivar		
	asparagus 'Mary Washington'	sweet corn 'Gold Cup'	tomato 'Heinz 1350'
Year	1978	1977	1978
Seeding date	4/16/74	5/25	5/26
Seeding method	--	V-belt	V-belt
Seeding depth (cm)	--	4.0	1.3
Formulation	granule	emulsion	granule
Placement	surface	drench (1300 l/ha)	seed, surface, sidedress
Treatment date	5/4	7/22	5/26,6/28,6/28
Soil type	Oshetemo sandy loam	Miami loam	Spinks sandy loam
Plot size (m)	1.2x7.6	0.9x7.6	1.2x7.6
Harvest date	5/8	8/15	9/11
Number of harvests	10	3	2

Table 9. (continued).

	Crop and Cultivar		
	asparagus 'Mary Washington'	sweet corn 'Gold Cup'	tomato 'Heinz 1350'
Fert applied	56 kg/ha NH_4 NO_3	504 kg/ha 12-12-12	560 kg/ha 5-20-20
Weed control	--	atrazine (1.1 kg a.i./ha)	metribuzin (0.3 kg a.i./ha)

Table 10. Cultural conditions of wheat receiving granular applications of TRIA in 1978.

	Location			
	East Lansing		Saranac	
Soil type	Conover loam		Matherton loam	
Cultivar	'Ionia'	'Yorkstar'	'Ionia'	'Yorkstar'
Stage of crop and date				
Early tiller	4/27	4/27	4/27	4/27
Boot	6/2	6/2	6/2	6/2
Post anthesis	6/22	6/22	6/27	6/27
Plot size (m)	1.2x4.9	1.2x4.9	1.2x4.9	1.2x4.9
Harvest date	8/1	8/1	7/28	7/28

RESULTS AND DISCUSSION

Seed Treatments

In 1977, seed soak experiments were performed on five different crops. There was no visible response on the subsequent growth of seedlings from seeds treated with TRIA compared to seeds soaked in DCM only (control). The lack of response to TRIA was also observed in the marketable yields of these crops (Table 11). A different set of experiments was carried out at the same time as the previous experiment to determine any difference between the effect of TRIA applied as a seed soak to alfalfa placed around the seeds during planting. TRIA again did not increase the yield of the crops, however, there was an increase in yield from seed soaking in DCM alone with the tomatoes (Table 12). Contrary to expectation, planting the seed with alfalfa did not increase the yield of sweet corn and tomato, while barley yields were decreased. In 1978, DCM or TRIA and DCM did not produce plants having higher yields than the controls when directly seeded in the field (data not presented).

It can be concluded that soaking seed of crops in a TRIA-DCM solution for direct seeding in the field is not a feasible means of TRIA application.

Applying TRIA to the seed used for the production of field transplants proved to be the only effective method of application to the seed in 1978. The fresh weight of transplants from TRIA-treated seedlings

Table 11. Yield of several vegetable crops when seed soaked in DCM-TRIA solution for one hour in 1977.

TRIA (mg/l)	Yield (metric tons/ha)				
	Cucumber	Carrot	Lettuce	Radish	Sweet corn
Control	20.7	24.6	14.8	2.0	13.2
DCM Control	19.9	24.1	11.1	2.0	13.2
.01	20.4	24.2	16.0	1.9	11.5
.1	20.7	24.1	15.0	1.8	12.2
1.0	19.4	23.2	15.8	1.9	12.6
10.0	20.7	23.7	12.8	1.9	12.5
Coefficient of variation (%)	9.6	5.1	18.4	7.5	13.5

Table 12. Yield of several crops with seed treatments of alfalfa and DCM-TRIA soaking in 1977.

Substance	Treatment rate						Yield (metric tons/ha)			
	sweet corn		barley		tomato				tomato[y]	
	(kg/ha)	(mg/l)	(kg/ha)	(mg/l)	(kg/ha)	(mg/l)	sweet corn	barley[z]	early	late
Control	0		0		0		19.5	3.16	6.2	25.9
Alfalfa	1		1		1		18.7	3.02	4.9	25.5
Alfalfa	10		10		10		18.9	2.53	3.9	24.6
Solvent Control		--		--		--	17.5	--	21.9	36.4
TRIA		0.01		0.01		0.01	19.4	3.26	21.4	35.9
TRIA		0.10		0.10		0.10	18.3	3.71	20.4	37.0

[z] F value for linear decrease in yield with alfalfa significant at 0.05 level.

[y] F value for DCM treated seed vs. no DCM significant at 0.01 level.

(8.0 g/plant) was larger than the non-soaked (5.1 g/plant) and DCM soaked (4.8 g/plant) seed at time of transplanting to the field. This TRIA response was maintained at harvest with the plants from TRIA-DCM treatments yielding 27% more fruit than the controls (Figure 1). TRIA at 50 and 500 mg/ha as a foliage application and 400, 1600, 6400 mg/ha as a granular application, were made to the plants when flowers first appeared in the field. These post-applications increased the yield 13% over non-treated controls, however, a yield decrease of 12% occurred when plants from pretreated seed received post-applications. This is the only study in either year that shows a decrease in yield from multiple applications of TRIA.

Placement of the granular formulation of TRIA with the seed of cucumbers also was not an effective mode of application (Table 13). The yield of non-treated plots was significantly larger than the granular blank plots. Therefore, the granules, when placed with the seed, had a detrimental effect on cucumber yield. However, a comparison of all TRIA treatments to granular blank showed significantly higher yields for TRIA plots indicating that this effect was overcome by TRIA.

Foliar Treatments

Applying TRIA as a foliage spray when the plants had 2-3 true leaves proved to be an effective method of treatment for several crops in both years of study. However, in only a few cases could increased growth be observed; for example, the average height of all sweet corn treatments was 13% higher than the controls 15 days after treatment (Table 14). The overall yield of sweet corn was increased 16% by TRIA applications, this increase could not be attributed to either ear number

Figure 1. A comparison of 'Heinz 1350' tomato yield from TRIA treatments applied to the seed and to plants after flowering in the field.

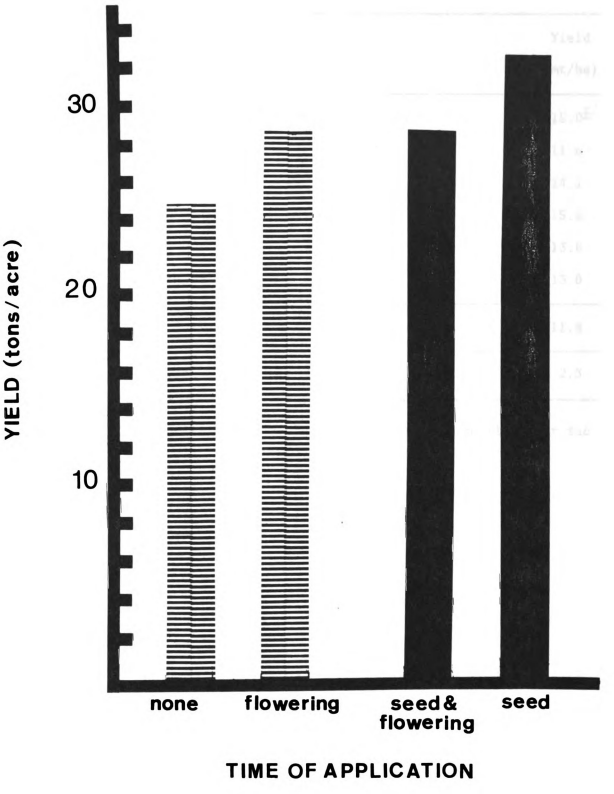

YIELD (tons/acre)
30
20
10
none
flowering
seed & flowering
seed
TIME OF APPLICATION

Table 13. Response of 'Green Star' pickling cucumbers to TRIA applied as a granular formulation with the seed in 1978.

TRIA (mg/ha)	Yield (mt/ha)
--	15.0[z/]
Granular blank	11.6
40	14.1
160	15.6
640	13.8
2560	13.0
Coefficient of variation (%)	11.4
L.S.D. at 0.01 level	2.5

[z/] F value for granular blank vs. TRIA treatments is significant at the 0.01 level.

Table 14. Yield of several crops receiving foliar applications of TRIA in 1977.

TRIA (mg/l)	Crop: sweet corn 'Gold Cup' plant ht (cm)	sweet corn 'Gold Cup' (mt/ha)	Lettuce 'Buttercrunch' (mt/ha)	tomato[w] 'Heinz 1350' (kg/plant)	radish 'Cherry Bell' (mt/ha)	cucumber 'Premier' (mt/ha)	cucumber 'Premier' fruit (no/plot)
Control	52[z]	10.76[z]	17.52	1.76[v]	1.81[y]	9.98[x]	99[x]
Emulsion control	--	--	21.13	--	1.81	--	--
0.01	58	11.91	16.48	--	1.71	11.83	117
0.05	--	--	20.03	--	--	--	--
0.1	60	13.37	23.92	--	1.86	11.45	116
1.0	58	12.03	19.37	--	1.95	11.20	109
10.0	59	12.53	--	2.96	--	10.55	105
100	--	--	--	3.60	--	--	--
1000	--	--	--	2.04	--	--	--

[z] F value for treatments compared to control significant at the 0.01 level.

[y] F value for linear trend with rate of TRIA significant at the 0.05 level, when average of controls used for zero level.

[x] F value for quadratic comparison significant at the 0.01 level.

[w] Individual plants were used as plots.

[v] F value for quadratic comparison significant at the 0.05 level.

or weight/ear alone, but a combination of these factors. Cucumber yield was increased an average of 13% by TRIA applications and could be attributed to an increase in number of fruit (13%) in treated plots. Yields of radishes exhibited a linear trend with increasing rates of application. Since the yield of fruit from individual tomato plants sprayed with high or low rates of TRIA was similar, it can be concluded that high rates of TRIA (1000 mg/l) did not injure plants.

The effect of multiple applications of TRIA was studied on cucumber, navy bean and tomato plants. The crops were treated initially at the young seedling stage, with the exception of the tomatoes which received initial treatments at first flowering, and received additional applications at weekly or bi-weekly intervals throughout the growing season. Rates of 0.01, 0.10 and 1.00 mg/l were applied to the navy beans and cucumbers while the tomatoes received rates of 1.0 and 10.0 mg/l throughout the season. These rates were applied with each of the application treatments on different plots, but there was no significant difference between rates and there was no interaction of rates with number of applications (Table 15). The navy bean and cucumber plots treated with TRIA compared to controls exhibited 7% and 11% yield increases for each crop. Sprays applied to transplanted tomatoes at different nitrogen levels increased the early yield by 14% while having no effect on late yield. There was no significant difference in yield at the two nitrogen levels and no interaction of TRIA application with nitrogen levels. These studies of crops which received multiple applications of TRIA showed no greater increase of growth than from a single application. There were no clear differences in yield at the rates applied in these studies.

Table 15. The yield of several crops receiving single or multiple applications of TRIA in 1977.

Number of applications	cucumber[z,y] 'Green Star' (mt/ha)	dry bean[x] 'Sanilar' (mt/ha)	tomato 'Heinz 1350' (mt/ha)	
			early[x]	late
Control	14.72	2.41	9.40	30.0
Single	16.01	2.64	11.03	32.9
Multiple	16.58	2.56	10.53	30.9

[z] F value for control vs. treatment significant at the 0.01 level.

[y] F value for linear trend with increasing number of applications significant at the 0.01 level.

[x] F value for control vs. treatment significant at the 0.05 level.

Wheat, navy bean and tomato crops were treated with TRIA at different stages of growth in an attempt to determine the optimum morphological stage of growth for application. In the wheat tests, foliar and granular treatments were applied at early tiller, boot and post-anthesis stages of growth. There were no significant differences due to formulation or time of application (Table 16). There was a quadratic trend for the increase in yield with different rates for the different cultivars at both locations. At East Lansing, there was an increase in yield from TRIA applications for 'Yorkstar', but not 'Ionia'. At the Saranac location, there was an increase in yield from TRIA applications for 'Ionia', but not 'Yorkstar'. The yields of navy bean and tomato crops treated in early vegetative and reproductive stages of growth was not significantly increased, yet the data would indicate a response to TRIA (Table 17). There was no interaction or rate with time of application in either crop. The same rates applied to cucumbers at the 2nd-leaf stage of development, increased the yield as indicated by a cubic trend with increasing rates of application. The data from the three crops (Table 17) were analyzed as percent of controls and split for crops. Controls were averaged in the three crops. The data for each rate of application and age were averaged in the tomato and navy bean crops. The average of all treatments, 105%, versus controls was significantly higher and the tomato crop responded significantly more to TRIA than either the cucumber or navy bean crops.

Nitrogen studies were conducted with sweet corn and carrots. Yields of carrots indicate that when TRIA was applied at low nitrogen levels there was a linear increase in yield ranging from 11% to 21% when compared to controls (Figure 2). However, with applications to carrots

Table 16. Response of wheat cultivars to TRIA applied in different formulations, times and rates at Saranac and East Lansing in 1978. Each observation is the average for the different times and rates of applications.

Treatment		Yield[y]	
Cultivar	TRIA[z]	East Lansing (bu/a)	Saranac (bu/a)
'Ionia'	0	50.5	46.4
	low	48.0	50.1
	medium	48.5	49.3
	high	49.7	48.2
'Yorkstar'	0	49.8	35.0
	low	50.8	35.4
	medium	51.3	34.2
	high	47.6	35.3

[z] Low, medium and high rates were 10, 40 and 160 and 40, 400 and 1600 mg TRIA/ha, respectively, for the emulsion and granular formulations.

[y] F value for the quadratic trend with different rates for the cultivars was significant at the 0.05 level at both locations.

Table 17. Yield of cucumber, tomato and navy bean crops when treated with foliar sprays of TRIA in 1978, and average yield analyzed as percent of controls in an analysis with crop as main plot.[z/]

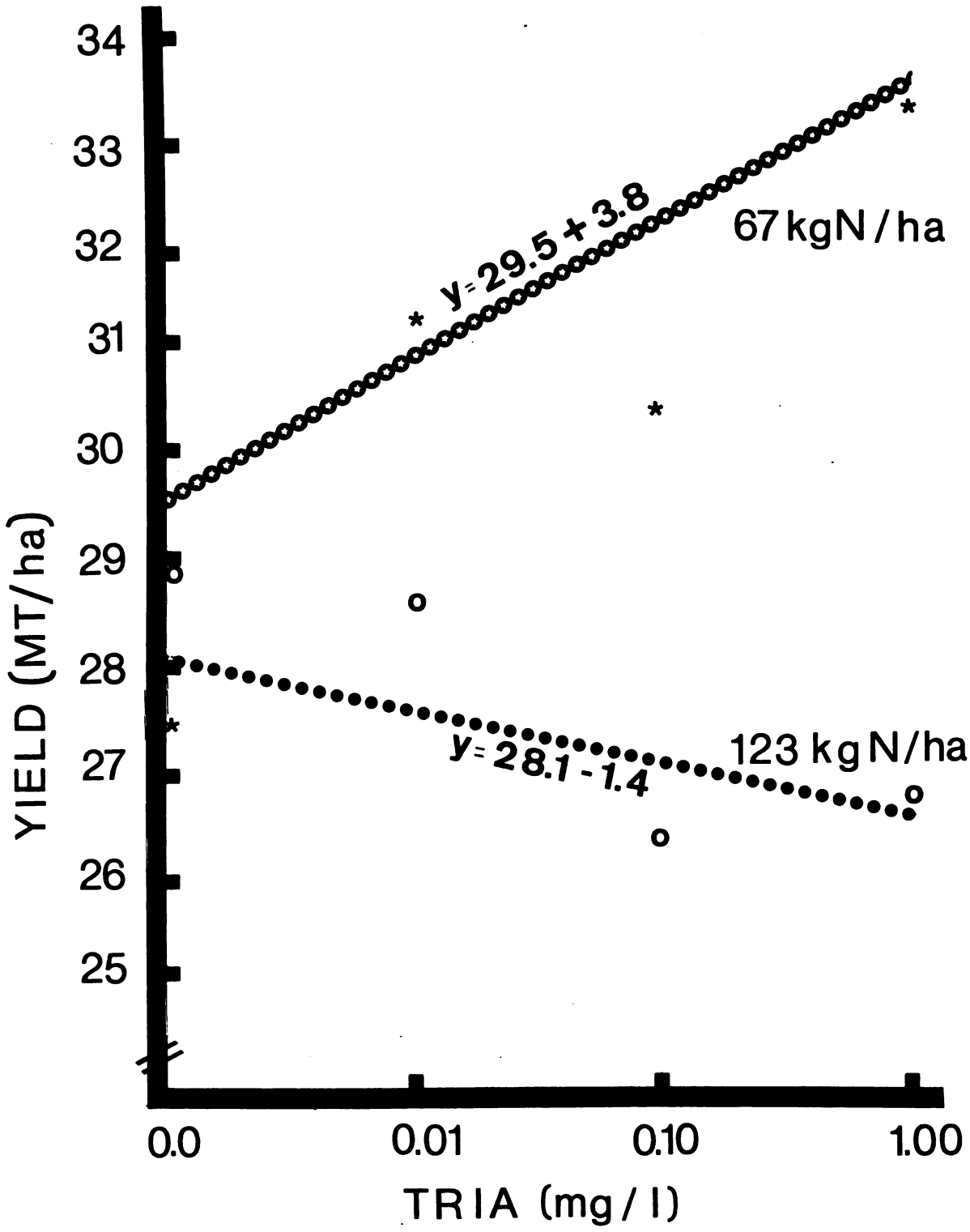
TRIA (mg/ha)	cucumber[y/] 'Green Star' (mt/ha)	navy bean 'Sanilac' (mt/ha)	tomato 'Heinz 1350' (mt/ha)	% of control for 3 crops[x/]
Controls	17.1	2.00	32.33	100
2.5	19.3	1.98	34.21	106
10.0	17.6	2.05	35.45	105
40.0	16.6	2.06	34.52	103
160.0	17.4	2.12	35.81	107

[z/] The yield from tomato and navy bean plots treated at early vegetative reproductive stages of growth was combined because there was no significant interaction of rate with age of application.

[y/] F value for cubic trend significant at the 0.05 level.

[x/] F value for treatments vs. controls significant at the 0.01 level.

Figure 2. Yield of 'Spartan Classic' carrots treated with TRIA at two different N levels. F value for linear trend in yield with different nitrogen levels significant at 0.05.


34
33
32
31
30
29
28
27
26
25
YIELD (MT/ha)
y=29.5+3.8
67 kgN/ha
y=28.1-1.4
123 kgN/ha
0.0
0.01
0.10
1.00
TRIA (mg/l)

growing under the higher N level there was a linear decrease in yield. In the sweet corn test with three N levels there was a quadratic rate response of TRIA with a linear rate of N supplied to the crop. The highest yields occurred at the low N level with the higher rates of TRIA and at the high N level with low rates of TRIA application (Figure 3).

Soil Treatments

Treatments were applied around the base of sweet corn plants with a high volume of TRIA solution to stimulate a soil drench. There was no response to the soil treatments (data not presented).

The effect of TRIA on asparagus was also studied. The high rate of TRIA granules (1.6 g/ha) applied to the soil surface increased the early yield 33% (Table 18). This rate when compared to all other treatments at different harvest times was significant at the 5% level. Neither the weight/spear nor the number of spears were solely responsible for the yield increase. In two other studies conducted in Oceana County, involving TRIA applications to asparagus, increases in yield were not observed.

Granular formulations of TRIA were applied with the seed, side-dressed (6.4 cm x 6.4 cm from seedlings) and on the soil surface of tomato plants. There was no significant increase in yield and no interaction of treatment with method of application (Table 19). However, inadequate controls were performed in this experiment since granular blank applied with the seed may be detrimental to yield (Table 13).

Figure 3. Yield of 'Gold Cup' sweet corn at different rates with different levels of N nutrition. F value for quadratic rate of TRIA with linear rate of nitrogen significant at 0.01 level.

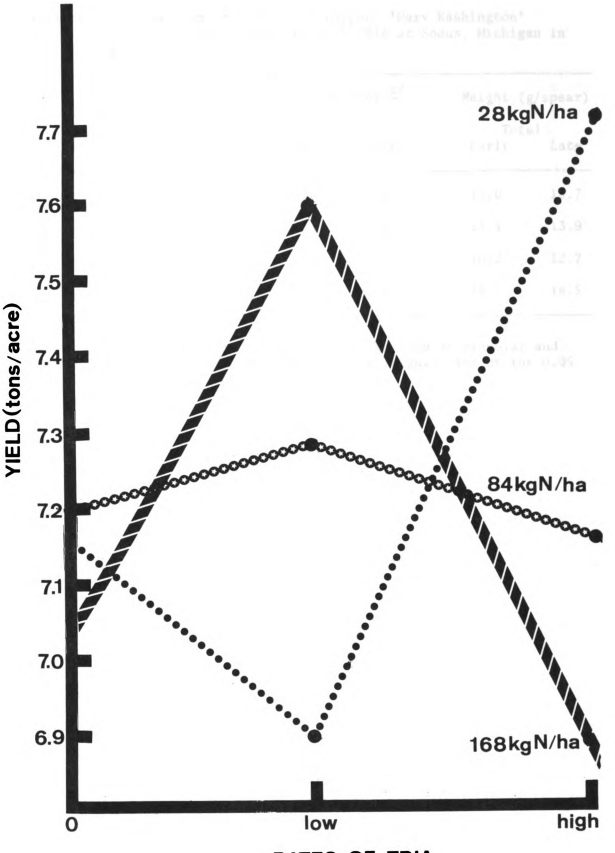

28kgN/ha
84kgN/ha
168kgN/ha
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
6.9
YIELD(tons/acre)
0
low
high
RATES OF TRIA

Table 18. A comparison of yield of "snapped" 'Mary Washington' asparagus after treatment with TRIA at Sodus, Michigan in 1978.

TRIA Formulation	TRIA (g/ha)	Yield (g/plot)[z/] Total Early	Yield (g/plot)[z/] Late	Weight (g/spear) Total Early	Weight (g/spear) Late
Control	0	616	308	14.0	15.7
Emulsion	0.04	661	236	14.4	13.9
Granular	0.40	671	313	16.2	12.7
Granular	1.60	819	228	14.8	14.5

[z/] F value for difference in yield between high rate of granular and other treatments at different harvest times significant at the 0.05 level for yield.

Table 19. Yield of 'Heinz 1350' direct seeded tomatoes as influenced by granular applications of TRIA.

Method of application	TRIA (mg/ha)	Yield (mt/ha)
Seed	Granular blank	37.7
	400	45.9
	1600	39.3
Sidedressed	Granular blank	37.0
	400	38.6
	1600	39.2
Surface	Granular blank	42.9
	400	39.1
	1600	40.1
Coefficient of variation (%)		14.3

CONCLUSION

Visual effects of TRIA were often not observed in the field, although increases in yield were measured. This may be due to biological variation among plants grown in the field since differences in growth were observed under the more uniform conditions of the greenhouse. Foliar sprays appear to be the most effective method of TRIA application. Foliar applications of TRIA from 20 mg/ha of crop to 2.2 g/ha were especially effective in increasing yield in the field applications. While there was no clear rate range, the plants response to TRIA is generally more consistent at lower concentrations of TRIA. High concentrations of TRIA (1000 mg/l) were not harmful to tomatoes. Single applications of TRIA were as effective as multiple applications. The morphological stage of growth did not affect the plants response to TRIA.

Seed soak applications of TRIA, while very effective in the greenhouse, do not increase growth of plants in the field, unless the seedlings are grown for field transplants.

The granular formulations of TRIA may increase the growth of the crops and more research is necessary to determine the best placement of the granules near the seed. Surface applications increased the yield of several crops, but it would appear that higher rates of TRIA are required for the yield response.

Nitrogen studies indicated that crops respond to a greater degree to TRIA when grown under low nitrogen regimes.

From observations of the 0.1% emulsion, it is thought that a greater effort in formulation is required as the concentrate is not stable at room temperature. Whether the greater variation was due to environment or cultural practices is not certain. Unpublished data (Ries, Wert) from greenhouse studies indicate that volume delivered may be a critical factor in the plants response to TRIA. This information may relate to the success of field applications in 1978, since substantially lower volumes were applied the second year of study.

TRIA, under conditions which were not made clear in this study, will increase the yield of several crops. This increase is not significantly consistent to suggest that TRIA be used by growers. More research must be conducted to determine the optimum parameters for commercial use of TRIA in the field.

LITERATURE CITED

1. Bittenbender, H. C., D. R. Dilley, V. F. Wert and S. K. Ries. 1978. Environmental parameters affecting dark response of rice seedlings to triacontanol. Plant Physiol. 61:831-854.

2. Chibnall, A. C., E. F. Williams, A. L. Latner and S. H. Piper. 1933. The isolation of n-triacontanol from lucerne wax. Biochem. J. 27:1885-1888.

3. Hangarter, R., S. K. Ries and P. Carlson. 1978. Effect of triacontanol in plant cell cultures in vitro. Plant Physiol. 61:855-858.

4. Jones, J. F., V. F. Wert and S. K. Ries. 1979. Specificity of 1-triacontanol as a plant growth stimulator and inhibition of its effect by other long-chain compounds. Planta 144:277-282.

5. Kolattukudy, P. E. and T. J. Walton. 1972. The biochemistry of plant cuticular lipids. Prog. Chem. 13:121-175.

6. Kolker, L. 1978. Analytical procedures for 1-triacontanol and its presence in plants and the environment. M.S. Thesis, Michigan State University.

7. Martin, J. T. and B. E. Juniper. 1970. The cuticles of plants. Edward Arnold Ltd., N.Y., pp. 347.

8. Ries, S. K., H. Bittenbender, R. Hangarter, L. Kolker, G. Morris and V. Wert. 1976. Improved growth and yield from organic supplements. In: W. Lokeretz, ed. Energy and Agriculture. Acad. Press, N.Y., pp. 377-394 (1977).

9. Ries, S. K., T. L. Richman and V. Wert. 1978. Growth and yield of crops treated with triacontanol. Amer. Soc. Hort. Sci. 103: 361-364.

10. Ries, S. K. and V. Wert. 1977. Growth responses of rice seedlings to triacontanol in light and dark. Planta 135:77-82.

11. Ries, S. K., V. Wert, C. C. Sweeley and R. A. Leavitt. 1977. Triacontanol: A new naturally occurring plant growth regulator. Science 195:1339-1341.

12. Waldron, J. D., D. S. Gowers, A. C. Chibnall and S. H. Piper. 1961. Further observations on the paraffins and primary alcohols of plant waxes. Biochem. J. 78:435-442.