CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM

A. Project Title: Evaluation of Slow Release Fertilizers for Cool Season Vegetable Production in the Salinas Valley

CDFA Contract Number: 00-0506

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B. Objectives - Year Three

Objective 1: Evaluate nitrogen release, yield impacts and the economics of the use of slow release fertilizer materials on winter broccoli.

Objective 2: Distribute the results of the research through appropriate extension activities such as meetings, field days, and newsletters.

C. Executive Summary:

Slow release fertilizers have the potential to provide a best management practice (BMP) that growers can utilize to reduce nitrate leaching from vegetables that are produced during the winter when the highest rainfall and greatest potential for leaching occurs. Slow release fertilizers have not been extensively investigated in cool season vegetable production systems. As a result, there are questions regarding 1) the release pattern of the slow release materials and how they mesh with the uptake demand of cool-season vegetables, and 2) the cost of slow release materials. Slow release fertilizers were evaluated on winter-grown broccoli in three field trials from 2000-2003. Broccoli was selected as the test crop because it is extensively planted and winter-grown broccoli is produced during the rainiest time of the year when the potential for leaching of nitrate is highest.

These trials were conducted in the "real world" conditions of the Salinas Valley. There are high residual levels of nitrate-N in the soil at the onset of winter in Salinas Valley soils in addition, there was low rainfall over the course of the trials. Both of these factors resulted in high background levels of soil nitrate -N at the onset of the trials that made it difficult to detect subtle differences in yield between the fertilizer treatments and to determine their impact on nitrate leaching and nitrogen use efficiency. In spite of these obstacles we detected differences amongst the fertilizer treatments, but the differences do not appear to be as dramatic and favorable to the use of slow release fertilizers as has been observed in other trials on sandy soils with low residual nitrogen and furrow irrigation.

Field Trial Evaluation: This trial was the third and final year of evaluation of slow release fertilizers on winter-grown broccoli. The slow release fertilizer was applied on November 15, 2002 four inches below and two inches to the outside of the seedline. Two hundred pounds per acre of nitrogen (N) was applied to each fertilizer treatment (table 1). The slow release fertilizer treatments had 100, 75 or 50% of the total amount of N applied as slow release fertilizer followed by 0, 25 or 50% of the remainder of the N applied as ammonium nitrate in one or two subsequent sidedress applications, respectively. The two slow release fertilizer materials tested in these evaluations were Duration® (Agrium Corp.) and Polyor® (Simplot Corp.).

There were high levels of residual nitrate-N in the soil at the beginning of the trial and no separation amongst the treatments in soil nitrate-N levels was observed until after the January 2d sampling date, at which time the untreated control had less soil nitrate than the other treatments (tables 3 and 4). The soil nitrate-N in the slow release treatments generally declined steadily over the course of the season, while the standard and combination slow release fertilizer treatments spiked higher soil nitrate-N values following sidedress fertilizer applications. There were small differences in the levels of tissue nitrate and total nitrogen between the fertilizer treatments but most treatments had higher levels than the untreated control (table 5).

Soil samples at one-foot increments down to three feet were collected at the beginning and at the end of the growing season and the samples were analyzed for nitrate and ammonium. This is the first year of the three years of this study that we detected significantly higher levels of soil nitrate-N in the standard fertilizer treatment than in the slow release and untreated control treatments at the three foot soil depth (tables 6 and 7). This observation may indicate that less leaching of nitrate may potentially occur with slow release fertilizers.

There was significantly greater broccoli head biomass in the standard fertilizer and all slow release fertilizer treatments than the untreated control on the first harvest date (table 8). The total number and weight of broccoli heads harvested from the standard and all slow release fertilizer treatments were comparable.

Three Year Summary

These trials presented challenges for accurately determining the efficacy of the two slow release materials tested. The Salinas Valley is intensively farmed and prior studies have shown high residual soil levels of nitrate-nitrogen in the soil in the late fall at the end of the growing season. Mean soil levels down to three feet at the beginning of the trials were 43.6, 40.5 and 31.3 ppm nitrate nitrogen in the first, second and third years of this project, respectively. A quick calculation of the amount of residual nitrogen in the soil at the beginning of each trial indicates a large supply of nitrogen. In addition, essentially no significant leaching rainfall fell during the course of the three trials: 8.79, 4.70 and 5.79 inches fell in years one, two and three, respectively. Higher rainfall could have reduced the impact of the high residual nitrogen on the trials by leaching it below the root zone. In spite of these two factors, the broccoli crop responded to applied fertilizer. All fertilizer treatments maintained greater soil nitrate-N levels in the soil over the course of the growing season than the untreated control, but none of the slow release fertilizer treatments had greater soil nitrate-N than the standard fertilizer treatment.

The fertilizer treatments improved the yield of broccoli over the three years of trials (table 10). None of the slow release trials improved the yield over the standard fertilizer treatment, but there is some indication that Polyon treated plots may have had slightly greater yield than Duration.

We observe reduced nitrate in the two to three foot soil depth at the end of the trial in the slow release fertilizer treatments in the 2002-2003 trial only (table 7). The high levels of residual nitrogen present at the beginning of the trials in each year made it difficult to detect these differences at the end of the cropping season , presumably by "washing out" differences between treatments. However, this observation may be significant because it provides a piece of evidence that slow release fertilizers may be able to play a role in reducing nitrate leaching and could provide a Best Management Practice (BMP) for growers, although it is unfortunate that this project could not be more conclusive in this regard.

The cost of fertilizer programs that utilize 100, 75 and 50% slow release fertilizers in a typical broccoli fertilizer program (i.e. 232 lbs N/A) are 31, 26 and 22% more than the standard fertilizer program (table 11). Given the higher cost of slow release fertilizer and the lack of improved yields over the standard fertilizer treatment, slow release fertilizers may only be a reasonable fertilizer practice for over-wintered broccoli on light soils in years when high rainfall is expected that may inhibit timely sidedress applications of conventional fertilizer.

D. Work Description - Year Three:

Task 1.1: One slow release fertilizer trials was conducted in a commercial broccoli field in the Salinas Valley in 2002-03. An over-wintered field on light soils was selected for this trial to provide the greatest potential for exposure to the high rainfall months and greatest potential for nitrogen movement from the root zone.

Subtask 1.2 Biweekly soil and plant tissue samples will be collected from each treatment to evaluate the efficacy of the fertilizer treatments. Plant tissue will be monitored three times during the growing season by collecting leaf and petiole tissue and having it analyzed for total nitrogen and nitrate nitrogen at the DANR laboratory at U.C., Davis. Soil samples will be collected and extracted with 2M KCl and sent to the DANR laboratory for nitrate and ammonium analyses. A complete nutrient analysis will be conducted of the soil and the crop (at mid-growth) to evaluate the total nutritional status of the soil and crop.

Subtask 1.3: Soil will be sampled from the middle of each plot to 3 feet deep, at one-foot intervals, at the beginning of the trial and at harvest to determine the movement of nitrogen below the rooting zone of the broccoli during the winter. Samples will be collected from the center of each plot . Irrigation water will be analyzed for nitrate content to account for its contribution to the crop.

Subtask 1.4: Evaluations of commercial yield and packout as well as nitrogen evaluations of the crop will be made at harvest . Samples of broccoli at harvest will be taken and sent to the DANR laboratory for total nitrogen analysis.

Task 2: Conduct an outreach program to educate growers via publications , field meetings and tours on the applicability of slow release fertilizers on nitrogen utilization and efficiency. The purpose of this task is to extend to growers , fertilizer company representatives, PCAs and other related industry representatives the results of the slow release trials and encourage consideration of this technology as a potential means to manage fertilizer nitrogen in the winter. The products of this task will include at least one grower meeting, field day or tour . Articles will be submitted to local newsletters and agricultural news media . Presentations will be made to local nutrient management and crop production meetings as well as the FREP Conference. A final report of outreach efforts will be made to CDFA no later than 2/04.

Subtask 2.1: Conduct grower meetings or a field day to provide growers and allied industry representatives an opportunity to learn about and discuss results. Present results at the annual FREP conference.

Subtask 2.2: Publish articles in *Monterey County Crop Notes* (distribution 1,700) and other farm industry publications.

E. Results, Discussion and Conclusion:

Task 1: Field trial study:

Subtask 1.1: One slow release fertilizer trials was conducted in a commercial broccoli field in the Salinas Valley in 2002-03. An over-wintered field on light Chualar loam soil was selected for this trial to provide the greatest potential for exposure to the high rainfall months and greatest potential for nitrogen movement from the root zone. The trial was a randomized complete block design and each plot was 4 forty-inch beds wide by 50 feet long. The slow release fertilizer was applied on November 18, 2002 with a small plot fertilizer applicator that shanked the fertilizer four inches below and two inches to the outside of the seedline. The trial was direct seeded on November 24, 2002 with the variety Marathon. Two hundred pounds of nitrogen (N) per acre were applied to all fertilizer treatments. In addition to evaluating two materials, the trial evaluated three strategies for the use of the slow release materials: 100, 75 or 50% as slow release materials applied preplant, followed by 0, 25 and 50% of the remainder of the N as one or two sidedress N applications of ammonium nitrate. These treatments were compared with a standard practice and an untreated control (See table 1). A total of 56 lbs/A of N were applied to the trial from other sources (table 2).

Subtask 1.2: Biweekly soil samples were collected from the seedline of the middle two rows of each plot, immediately extracted with 2M KCl, process and submitted to the DANR Analytical laboratory at UC, Davis for nitrate and ammonium analysis. Tissue samples of the broccoli were collected from the most recently matured leaf from plants in the middle two rows of each plot at two times during the growing season and submitted to the laboratory for total nitrogen and nitrate analysis. There were high levels of residual nitrate-N in the soil at the beginning of the trial and the levels of soil nitrate-N in the untreated plots did not separate from the standard fertilizer treatment until after the January 2 sampling date (tables 3 and 4). These differences were reflected in differences in tissue nitrate and total-N in broccoli tissue on both sampling dates (table 5). The soil nitrate-N in the slow release treatments generally declined steadily over the course of the season, while the standard and combination slow release fertilizer treatments spiked higher soil nitrate-N values following sidedress fertilizer applications. Trends of mean soil nitrate-N levels over the three seasons of trials were difficult to interpret; however, all fertilizer treatments maintained higher soil nitrate-N levels than the untreated control (table 9).

Subtask 1.3: Soil samples to three feet deep at one-foot increments were collected at the beginning and at the end of the growing season. The samples were analyzed for nitrate and ammonium (tables 6 and 7). This is the first year of the three years of this study that we detected a difference between the levels of nitrate at the 3 foot soil depth between the slow release fertilizer treatments and the standard fertilizer treatment. There was a trend for greater nitrate at the three foot soil depth in the standard fertilizer treatment than slow release fertilizer treatments or the unfertilized control. This may indicate that slow release fertilizers may not leach nitrate as readily as standard fertilizer treatments. However, this conclusion is weakened by the fact that this observation was made in only one year out of the three years of trials. However, as was mentioned earlier, the high levels of residual soil N that occurred in each year of these trials may have made it difficult to observed differences in leaching of soil nitrogen amongst treatments.

Subtask 1.4: There was significantly greater broccoli head biomass in the standard and in all slow release fertilizer treatments than the untreated control on the first harvest date (table 8). The total number and weight of broccoli heads harvested from the standard and slow release fertilizer treatments were comparable. The mean broccoli yield over three years indicated that there were no differences amongst the fertilizer treatments and that all fertilizer treatments had greater broccoli weight and mean head weight than the untreated control (table 10).

The cost of fertilizer programs that utilize 100, 75 and 50% slow release fertilizers in a typical broccoli fertilizer program (i.e. 232 lbs N/A) are 31,
26 and 22% more than the standard fertilizer program, respectively (table 11).

Task 2: Outreach to growers

Complete List of Outreach Efforts by Richard Smith and Tim Hartz:

Year One

1) October 4, 2001 - Salinas Valley Farm Day, Salinas, CA
Slow release fertilizer studies on cool season vegetables
Richard Smith
Sponsor: CAPCA, Monterey Bay Chapter
Attendance: 75

2) October 9, 2001 - Lettuce Research Board Conference, Seaside, CA
Evaluation of slow release fertilizers for lettuce production (with reference to the FREP broccoli project)
Sponsor: California Lettuce Research Board
Attendance: 100

3) November 14, 2001 - 2001 FREP Conference, Tulare, CA
Comparative release rate from slow release nitrogen fertilizers
Tim Hartz
Sponsor: FREP
Attendance: 100

4) January 16, 2002 - Irrigation and Nutrient Management Conference, Salinas, CA
Slow release fertilizer evaluations on lettuce and broccoli
Richard Smith
Sponsor: UCCE, Monterey County and Monterey County Water Resources Agency
Attendance: 140

5) January 29, 2002 - Water Quality Short Course, Hollister, CA
Nitrogen fertilizer management of vegetables (including a discussion on the role slow release fertilizers in efficient nutrient management)
Richard Smith
Sponsor: UCCE, San Benito County
Attendance: 15

6) February 19, 2002 - Agricultural Seminar 2002
Slow release and organic fertilizers (translate to Spanish)
Richard Smith
Sponsor: Dr. Win Seminar
Attendance: 45

Year Two

7) March 12, 2002 - California Lettuce Research Board, Sacramento, CA
Slow release fertilizers for lettuce production (with comparison to broccoli)
Sponsor: California Lettuce Research Board
Attendance: 35

8) October 28, 2002 - California Lettuce Research Board, Seaside, CA
Slow release fertilizers for lettuce production (with comparison to broccoli)
Sponsor: California Lettuce Research Board
Attendance: 90

9) December 9, 2002 - Ventura County Vegetable Production Meeting, Oxnard, CA
Slow release fertilizers for lettuce and broccoli production
Sponsor: UCCE , Ventura County
Attendance: 25

10) January 16, 2003 - Fresno County Vegetable Production Meeting, Harris Ranch, CA
Slow release fertilizers for lettuce and broccoli production
Sponsor: UCCE , Fresno County
Attendance: 40

11) January 28, 2003 - Water Quality Short Course, Hollister, CA
Nutrient management for row crop production
Sponsor: UCCE, San Benito County
Attendance: 16

12) February 12, 2003 - 2003 Irrigation and Nutrient Management Meeting and Cover Crop Field Day, Salinas, CA
Slow release fertilizer for lettuce and broccoli production: a three year summary
Sponsor: UCCE, Monterey County and USDA Vegetable Research Station
Attendance: 90

13) February 26, 2003 -, ALBA training class for prospective growers, Salinas, CA
Fertilization of vegetables both conventional and organic (presentation given in Spanish)
Sponsor: ALBA
Attendance: 25

Y ear Three

14) March 13, 2003 - Hartnell Community College, Salinas, CA
Fertilizers and Fertilization of Row Crops (including the role of slow release fertilizers as fertilizers for crop production)
Sponsor: Hartnell College
Attendance: 19

15) March 4, 2003 - Farm Water Quality Planning Short Course, Coward Creek Watershed, Santa Cruz County, Watsonville, CA
Improving nutrient use efficiency in vegetable production (including the role of slow release fertilizers in nitrogen use efficiency) - Translated to Spanish
Sponsor : UCCE, Santa Cruz
County Attendance: 25

16) April 1, 2003 - California Coastal Nutrient Seminar for Vegetable Production, Watsonville, CA
The role of nitrogen and phosphorus use efficiency in complying with water quality issues (including the role of slow release fertilizers in nitrogen use efficiency)
Sponsor: Cal Agra, Agricultural Fertilizer Company
Attendance: 15

17) April 2, 2003 - California Coastal Nutrient Seminar for Vegetable Production, Salinas, CA
The role of nitrogen and phosphorus use efficiency in complying with water quality issues (including the role of slow release fertilizers in nitrogen use efficiency)
Sponsor: Cal Agra, Agricultural Fertilizer Company
Attendance: 20

18) March 20 , 2003 - Master Gardeners Training Class, Watsonville, CA
Basic soil science and soil fertility (including the role of slow release fertilizers as fertilizers for crop production)
Sponsor: UCCE, Santa Cruz County
Attendance: 40

19) July 16, 2003 - Coastal Agronomy Conference, Salinas, CA Slow release fertilizers for cool season vegetable production
Sponsor: California Plant Health Association
Attendance: 50

20) November 6, 2003 - Farm Water Quality Planning Short Course, Lower Salinas Valley and San Juan Watersheds , Monterey and San Benito Counties Salinas, CA
Improving nutrient use efficiency in vegetable production (including the role of slow release fertilizers in nitrogen use efficiency)
Sponsor: UCCE, Monterey County
Attendance: 43

21) November 20, 2003 - 2003 FREP Conference, Tulare, CA
Evaluation of slow release fertilizers for cool season vegetable production in the Salinas Valley
Sponsor: FREP Program
Attendance: 45

Publications:

Year One

Controlled Release Fertilizer Evaluation
Monterey County Crop Notes, September 2000
Richard Smith

Proceeding of the 2001 FREP Conference
Comparative release rate from slow release nitrogen fertilizers
Tim Hartz

Proceeding of the 2001 FREP Conference
Evaluation of Slow Release Fertilizers for Cool Season Vegetable Production in the Salinas Valley
Richard Smith

Evaluation of Slow Release Fertilizers for Winter Vegetable Production in the Salinas Valley
Monterey County Crop Notes, November 2001
Richard Smith

Year Two

Proceeding of the 2002 FREP Conference
Evaluation of Slow Release Fertilizers for Cool Season Vegetable Production in the Salinas Valley
Richard Smith

Slow Release Fertilizers Lettuce Production: A Three Year Summary
(not directly related to broccoli production, but did include have relevant concepts)
Monterey County Crop Notes, November 2002
Richard Smith

Year Three

Slow Release Fertilizers Broccoli Production: A Three Year Summary
Monterey County Crop Notes, November 2003
Richard Smith

Proceeding of the 2003 FREP Conference
Evaluation of Slow Release Fertilizers for Cool Season Vegetable Production in the Salinas Valley
Richard Smith

F. Project Evaluation

The costs for the use of slow release fertilizers are 22-33% greater than standard fertilizer. The lack of improved yields will limit the use of slow release fertilizer to years with high risk of being rained out of the fields to make timely sidedress fertilizer applications.

G. Outreach Activities Summary

For details see Task 2. This slow release fertilizer project through the FREP program on winter-grown broccoli occurred at the **same** time that I received funding from the lettuce board to examine slow release fertilizers on lettuce. As a result, many of the educational events that I organized or participated in over the past three years discussed both projects and provided a much more complete picture of the applicability of slow release fertilizers for cool season vegetables in the Salinas Valley. In some ways the two commodities provided a good opportunity to compare and contrast the strengths of the slow **release** materials. For instance, we saw a decrease in yield with 100% slow release fertilizers in lettuce which was not observed in broccoli. The information that we developed through these studies was thoroughly disseminated over the course of this project. I made a decision early on in this project to not have field days because the plots did not show dramatic differences amongst the plots. The field days were not critical to dissemination of the information of this project and we put a great deal of effort into disseminating the information through many other meetings in Monterey, Santa Cruz and San Benito Counties. The Lettuce Board Meetings provided access to key growers that grow both lettuce and broccoli and they were keenly interested in research results on slow release fertilizers for both commodities. The Water Quality Short Course meetings also had many key growers present and they were run more informally, and we had many good discussions on a wide range of fertilization issues including slow release fertilizers. I also made two presentations that were translated to Spanish for non-English speaking growers. I was also invited to speak out of the Central Coast Area and gave presentations at growers **meetings** in Fresno and Ventura Counties. I had three articles in *Monterey County Crop Notes* which is a key publication for the dissemination of research based information to Central Coast growers. In summary the results from this project were widely and thoroughly disseminate

Table 1. Fertilizer application schedule and total yield of broccoli

Treatment	11/18/02 lbs N/A	Sidedress #1 12/12/02	Sidedress #2 1/16/03	Sidedress #3 2/18/03	Sidedress #4 3/13/03
Polyon	200	0	0	0	0
Polyon	150	0	0	0	50
Polyon	100	0	50	0	50
Duration	200	0	0	0	0
Duration	150	0	0	0	50
Duration	100	0	50	0	50
Standard	0	50	50	50	50
Untreated	0	0	0	0	0

Table 2. Details of the slow release plot

Location	Soil Type	Planting Date	Harvest Dates	NO3-N in Water (ppm)	Water N contribution to crop (lbs)	Preplant N applied in the fall (lbs)	Total extra N applied to trials	Rainfall during trial (inches)
Gonzales	Gravelly loam	November 24, 2002	March 3 & 10, 2003	18	32	24	56	5.79

Table 3. Nitrate-nitrogen levels in the soil over the course of the growing season.

	14-Nov	12-Dec	2-Jan	16-Jan	28-Jan	25-Feb	13-Mar	10-Apr
Duration 100	42.7	36.0	7.7 b	7.6	8.1 b	12.5 a	10.1 ab	73.3 b
Duration 150	35.9	45.0	6.5 ab	5.9	5.3 ab	17.0 ab	10.5 ab	10.0 a
Duration 200	23.5	31.6	5.4 ab	9.7	8.8 b	15.4 a	6.6 ab	1.9 a
Polygon 100	16.2	32.4	5.0 ab	7.4	4.3 ab	10.8 a	2.1 a	5.8 a
Polygon 150	28.3	27.3	8.4 b	9.3	6.1 ab	10.7 a	13.2 ab	16.1 a
Polygon 200	26.1	40.2	8.7 b	8.4	7.5 b	13.5 a	7.1 ab	0.7 a
standard	32.4	32.1	7.9 b	8.7	22.9 c	26.5 b	28.2 b	61.6 b
untreated	21.7	29.9	3.3 a	3.1	1.6 a	8.6 a	3.2 a	1.4 a
LSD	*ns*	*ns*	*3.9*	*ns*	*5.6*	*9.9*	*24.3*	*40.25*

Table 4. Ammonium-nitrogen levels in the soil over the course of the growing season.

	14-Nov	12-Dec	2-Jan	16-Jan	28-Jan	25-Feb	13-Mar	10-Apr
Duration 100	1.8	2.1	1.6	1.5	7.7	4.0	2.2	7.1
Duration 150	1.5	2.3	1.6	1.1	1.4	6.0	3.4	6.6
Duration 200	1.8	2.5	1.7	1.4	3.8	5.7	3.0	1.8
Polygon 100	2.1	2.4	1.8	1.0	2.7	4.1	2.6	1.5
Polygon 150	1.9	1.6	1.8	1.1	1.7	2.7	5.9	18.8
Polygon 200	2.3	2.3	1.7	1.2	2.2	7.1	1.5	1.8
standard	4.0	3.3	3.3	1.6	9.5	3.7	9.1	39.5
untreated	3.1	3.2	1.7	2.0	1.3	4.6	3.4	1.9
LSD	*ns*	*1.14*	*ns*	*ns*	*7.50*	*3.00*	*ns*	*25.10*

Table 5. Nitrogen content of broccoli tissue on two sampling dates.

	NO3 TISSUE				N TISSUE			
	28-Jan		**28-Mar**		**28-Jan**		**28-Mar**	
Duration 100	7028	d	2020	c	5.55	b	5.32	b
Duration 150	4875	ab	1843	b	5.55	b	5.01	b
Duration 200	5413	bc	1768	b	5.65	c	5.37	b
Polygon 100	4300	ab	1968	b	5.55	b	5.06	b
Polygon 150	6385	c	2000	b	5.50	b	5.10	b
Polygon 200	5758	c	1665	b	5.60	b	5.02	b
standard	4530	ab	1960	b	5.45	ab	5.35	b
untreated	3488	a	1103	a	5.29	a	4.14	a
LSD	***1397***		***336***		***0.17***		***0.67***	

Table 6. Soil nitrate and ammonium-N at the beginning and at the end of the growing season in each treatment

Treatment	Sampling Depth	N03 -Nov	N03-April	NO3 Change	NH4 -Nov	NH4-April	NH4 Change
Duration 100	*0 – 1 foot*	42.71	73.34	30.63	1.76	7.13	5.37
	1 – 2 feet	63.88	24.09	-39.79	1.42	1.43	0.01
	2 – 3 feet	32.67	19.27	-13.41	0.75	1.33	0.58
Duration 150	*0 – 1 foot*	35.87	10.05	-25.82	1.54	6.57	5.03
	1 – 2 feet	54.25	8.42	-45.83	1.24	2.57	1.33
	2 – 3 feet	22.56	12.47	-10.09	1.11	1.51	0.40
Duration 200	*0 – 1 foot*	23.52	1.93	-21.59	1.75	1.82	0.07
	1 – 2 feet	37.36	15.72	-21.65	1.75	0.86	-0.89
	2 – 3 feet	11.83	9.84	-1.99	0.95	1.83	0.88
Polygon 100	*0 – 1 foot*	16.21	5.82	-10.39	2.14	1.55	-0.59
	1 – 2 feet	49.75	1.60	-48.16	1.49	0.92	-0.57
	2 – 3 feet	27.27	11.00	-16.27	2.09	1.17	-0.92
Polygon 150	*0 – 1 foot*	28.29	16.05	-12.24	1.88	18.81	16.93
	1 – 2 feet	48.90	9.58	-39.32	1.49	2.15	0.67
	2 – 3 feet	27.79	7.86	-19.94	1.16	0.83	-0.33
Polygon 200	*0 – 1 foot*	26.12	0.67	-25.45	2.33	1.79	-0.54
	1 – 2 feet	38.01	1.39	-36.62	1.80	1.57	-0.24
	2 – 3 feet	16.96	3.36	-13.60	1.17	2.52	1.35
standard	*0 – 1 foot*	32.41	61.58	29.16	3.96	39.54	35.59
	1 – 2 feet	31.42	15.52	-15.90	1.20	2.12	0.92
	2 – 3 feet	14.11	17.75	3.64	1.02	1.07	0.05
untreated	*0 – 1 foot*	21.65	1.41	-20.24	3.05	1.93	-1.12
	1 – 2 feet	29.58	9.96	-19.61	1.85	0.96	-0.89
	2 – 3 feet	17.71	7.75	-9.97	1.08	0.86	-0.22
	LSD (0.05)	*27.42*	*25*	*34.8*	*1.8*	*14.3*	*13.9*
Contrasts[1]							
Polyon vsDuration		n.s.	*	n.s.	n.s.	n.s.	n.s.
Slow Release vs Standard		n.s.	*	*	n.s.	**	**
200 slow release vs Standard		n.s.	**	*	n.s.	**	**
200 vs 100 slow release		n.s.	*	n.s.	n.s.	n.s.	n.s.

1: * $P < 0.05$; ** $P < 0.01$

Table 7. Nitrate nitrogen in the soil at the end of the growing season and differences between nitrate-N levels in those treatments at the beginning and end of the season

Treatment	N03 -Nov		N03-April		NO3 Change		NH4 -Nov		NH4-April		NH4 Change	
Duration 100	46.4	b	38.9	a	-7.5	b	1.3	a	3.3	a	2.0	a
Duration 150	37.6	ab	10.3	a	-27.2	a	1.3	a	3.6	a	2.3	a
Duration 200	24.2	a	9.2	a	-15.1	a	1.5	a	1.5	a	0.0	a
Polygon 100	31.1	a	6.1	a	-24.9	a	1.9	a	1.2	a	-0.7	a
Polygon 150	35.0	ab	11.2	a	-23.8	a	1.5	a	7.3	b	5.8	b
Polygon 200	27.0	a	1.8	a	-25.2	a	1.8	a	2.0	a	0.2	a
standard	26.0	a	31.6	b	5.6	b	2.1	a	14.2	b	12.2	b
untreated	23.0	a	6.4	b	-16.6	a	2.0	a	1.3	a	-0.7	a
LSD	***14.6***		***16.9***		***20.6***		***ns***		***9.4***		***9.04***	
Depth 1	28.3		21.4		-7.0		2.3		9.9		7.6	
Depth 2	44.1		10.8		-33.4		1.5		1.6		0.0	
Depth 3	21.4		11.2		-10.2		1.2		1.4		0.2	
p-value	**0.0000**		**0.0761**		**0.0001**		**0.0018**		**0.0054**		**0.0112**	

Table 8. Yield of broccoli

Treatment	Number 1		Weight 1		Number 2		Weight 2		Total Number	Total Weight	
Duration 100	152.0	b	74.6	b	35	ab	9.8	a	187	84.4	b
Duration 150	137.0	ab	76.3	b	46	bc	12.8	ab	183	89	b
Duration 200	150.0	b	75.7	b	31	ab	8.5	a	181	84.2	b
Polygon 100	154.0	b	78.7	b	39	ab	11.4	a	193	90	b
Polygon 150	148.0	ab	77.6	b	41	ab	11.5	a	189	89.1	b
Polygon 200	147.0	ab	73.9	b	28	ab	8.3	a	175	82.2	ab
standard	132.0	ab	67.9	b	59	cd	18.1	b	190	86	b
untreated	108.0	a	47.2	a	71	d	24.3	c	178	71.5	a
LSD	***41***		***15.8***		***16.9***		***5.8***		***ns***	***12.2***	

Table 9. Mean nitrate nitrogen in the soil over three seasons.

Treatment	2001	2002	2003	Over All Mean
Untreated	15.3	21.3	9.08	15.2
Standard	20.2	25.4	27.54	24.4
Polyon 200	36.5	23.6	14.02	24.7
Polyon 150[1]	29.3	25.5	14.91	23.2
Polyon 100[2]	21.7	26.3	10.49	19.4
Duration 200	29.0	27.8	12.87	23.2
Duration 150[1]	28.7	26.3	17.01	24.0
Duration 100[2]	24.7	31.7	24.75	27.5
LSD (0.05)	19.1	4.1	10.4	9.2
Contrasts[3]				
Polyon vs Duration	n.s.	*	n.s.	n.s.
Standard vs Slow	n.s.	n.s.	*	n.s.
200 Slow vs Standard	**	n.s.	*	n.s.
200 Slow vs 100 Slow	**	*	n.s.	n.s.

1: slow release application was followed by one sidedress of 50 lbs N/A; 2: slow release application was followed by two sidedress applications of 50 lbs N/A each; 3: * $P < 0.05$; ** $P < 0.01$

Table 10. Mean yield of broccoli – mean of three years

Treatment	Total No. Heads	Total Wt. (lbs)	Mean Head Wt.
Untreated	173.0	80.5	0.46
Standard	177.5	87.3	0.50
Polyon 200	170.4	88.2	0.51
Polyon 150	178.5	89.4	0.50
Polyon 100	177.8	88.8	0.50
Duration 200	173.5	86.1	0.50
Duration 150	171.8	85.6	0.50
Duration 100	173.2	85.3	0.50
LSD (0.05)	n.s.	4.5	0.03
Contrasts[1]			
Polyon vs Duration	n.s.	*	n.s.
Standard vs Slow	n.s.	n.s.	n.s.
200 Slow vs Standard	n.s.	n.s.	n.s.
200 Slow vs 100 Slow	n.s.	n.s.	n.s.

1: * = 0.05

Table 11. Cost comparison summary for standard and slow release fertilizer applied to winter grown broccoli (232 lbs N/A applied)

Application	Fertilizer Type	Standard Fertilizer Program			Slow Release Fertilizer Programs								
			Costs/A		100% Slow Release			75% Slow Release			50% Slow Release		
		N/A (Lbs)	Fertilizer	Labor	N/A (Lbs)	Costs/A Fertilizer	Labor	N/A (Lbs)	Costs/A Fertilizer	Labor	N/A (Lbs)	Costs/A Fertilizer	Labor
Preplant	15-15-15	60[1]	28	15	200[4]	164	15	150[4]	123	15	100[4]	82	15
Sidedress #1	AN 20	60[2]	29	10	0	0	0	0	0	0	50[2]	24	10
Sidedress #2	AN 20	72[2]	34	10	0	0	0	50[2]	24	10	50[2]	24	10
Water run	CAN 17	40[3]	24	8	32[3]	19	8	32[3]	19	8	32[3]	19	8
Subtotal		232	115	43	232	183	23	232	166	33	232	149	43
Total Costs/A				**158**			**206**			**199**			**192**

1 - $0.47/lb N (cost of the 15-15-15 assigned to N); 2 – $0.47/lb N; 3 - $0.59/lb N; 4 – slow release @ $0.82/lb N.