Determination of Best Nitrogen Management Practices for Broccoli Production in the San Joaquin Valley

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Objectives
The primary objectives are to determine nitrogen fertilizer best management practices (BMPs) for broccoli production in the San Joaquin Valley through field research, to determine if BMPs change for fall versus spring harvested broccoli, and to identify nitrate movement and potential nitrate leaching losses of applied nitrogen fertilizer under furrow irrigation. A secondary objective is to evaluate the effectiveness and utility of the "Cardy meter" for quick test nitrate values for decision-making in broccoli nitrogen management during fall and spring growing seasons. Additional objectives include conducting grower/industry education programs to discuss the research results obtained and to influence and emphasize best management fertilizer practices.

Summary
Four broccoli field tests were conducted at the UC West Side Research and Extension Center. Thirteen nitrogen fertilizer treatments looking at nitrogen rate and timing were investigated in each study. Soil samples, plant tissue and whole plant samples, and ion exchange resin (IER) bag samples were collected to measure nitrogen and nitrate pools within the soil, plant, and/or leachate water of the broccoli cropping system, in an attempt to determine nitrogen BMPs for broccoli. Yield and broccoli quality measurements were also collected.

Expected outcomes were that nitrogen applications positively affected plant growth and yield and that relatively large amounts of nitrogen were needed to reach maximum yields. Differences were found between spring and fall harvested broccoli crops, although the differences were not as great as expected. Postharvest soil and IER bag samples helped determine BMP practices with respect to timing of N application that could significantly reduce environmental pollution and waste of resources. The Cardy meter proved not to be as useful a tool for quick nitrate testing when critical decision making is most needed.

This report summarizes the results of the four field studies and discusses best nitrogen management practices for broccoli production in the San Joaquin Valley.

Work Description (materials and methods)

Broccoli Field Trials

Four broccoli nitrogen fertilizer trials were conducted at the UC West Side Research and Extension Center in Five Points, CA, 50 miles west of Fresno. Soil type of the field station is a Panoche clay loam. For the purpose of these trials, fields presumed low in residual soil nitrogen content were selected. Two trials were planted for a spring harvest and two trials were planted and grown for a fall harvest. They will be referred to as:

Trial #1	Spring 1996	or	SP 96
Trial #2	Fall 1996	or	FA 96
Trial #3	Spring 1997	or	SP 97
Trial #4	Fall 1997	or	FA 97

Specific information relevant to the planting and data collection of each trial is listed in Table 1.

The 13 nitrogen treatments ranged from a total of 0 to 300 lbs nitrogen per acre. One treatment (a check plot) investigated zero applied nitrogen fertilizer. Five treatments involved split applications at preplant, thinning (sidedress 1), and layby (sidedress 2) with lesser rates of nitrogen applied preplant and at thinning and twice the rate applied at layby. These will be referred to as PSS treatments and are presumed to be the BMP applications because higher nitrogen rates are being applied when the plant root system is larger and in theory there is the potential for less resource waste and environmental pollution. Five other treatments looked at two equal split applications of the total applied nitrogen; one preplant application and one sidedress application at thinning. These are referred to as PS treatments. The last two treatments investigated high rates of nitrogen (240 lbs/A) applied in a single application either at preplant (P) or at thinning (S). Table 2 lists the 13 nitrogen fertilizer treatments and timing of application.

Preplant Soil Samples

An intensive and extensive soil sampling was conducted on each 1.25 acre site prior to planting. Preplant soil samples at five depths by one foot increments down to 5 feet were collected from 44 locations (future individual plots) with a Giddings soil sampler and submitted to the UC DANR laboratory for determination of nitrate following the KCl extract procedure.

Ion Exchange Resin Bags

Ten gram ion exchange resin bags were handmade and pretreated as described by Wyland and Jackson[1] before being carefully installed 1½ and 3 feet (45 and 90 cm, respectively) deep in 44 of the 52 plots

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[1] L. J. Wyland and L. E. Jackson, Evaluating Nitrate Recovery by Ion-Exchange Resin Bags, *Soil Science Society of America Journal*, Madison, WI, Vol. 47, No. 5, September-October 1993, pp. 1208-1211.

Planting Method & Experimental Design

Broccoli was direct seeded two rows per 40-inch bed and thinned to a 6-inch spacing between plants approximately 30-60 days after seeding (DAS). Plot size was four beds wide by 50 feet long, and the field experiment was arranged in a randomized complete block design. All samples and data were collected from the two middle beds. A 10-25 foot buffer area of broccoli surrounded the entire experiment.

Nitrogen Application

Each field was uniformly fertilized with 100 lbs P_2O_5 (treble super phosphate) per acre applied in a band before the preplant nitrogen fertilizer (in the form of urea) treatments were drilled in the field with a fertilizer rig adapted for small plot work. Two nitrogen fertilizer (urea) sidedress applications were made at thinning and at layby except in the Spring 1996 trial because excessive rainfall and wet conditions kept the equipment out of the field. (This trial was omitted from the combined year statistical analysis).

Petiole Samples

Petiole samples were collected from 11 of 13 treatments four times throughout the growing season: 4 true leaves (thinning), 8 true leaves, 16 true leaves (or button, start of head, formation), and at harvest with heads 1-5” in diameter. The first petiole sample was collected prior to the first sidedress application of fertilizer. At thinning, 80 petioles were collected from each plot, then divided into two halves. One half was dried and sent to the laboratory for nitrate analysis, while the other half was subjected to fresh sap analysis with the Cardy meter. As the broccoli plants grew, 60 and later only 40 petioles were collected from each plot.

Whole Plant Samples

Whole plant samples were also collected four times during the growing season, and their wet and dry weights were recorded. All samples were submitted to the UC DANR lab for percent total nitrogen content.

Midseason Soil Samples

Soil samples could not be collected during the growing season because it was determined that the sampling process was too destructive to the field experiment.

Harvest Data

Plots were hand harvested and evaluated for yield per acre and weight per head. All heads (regardless of size) were weighed as a gross yield and individual head weight was determined by dividing total weight by total head number. Other head quality characteristics other than size were not affected by the fertilizer treatments.

Postharvest Soil Samples and Ion Exchange Resin Bags

Postharvest soil samples were collected at five depths by one-foot increments down to 5 feet from 44 locations as outlined in Subtask .1. The ion exchange resin bags were also excavated and immediately subjected to a series of four rinses in 2N KCl as outlined by Wyland and Jackson[1]. Each rinse was sent to the UC DANR laboratory for nitrate analysis, and all four rinses were added to approximate total nitrate nitrogen leached through the soil at the 1.5 and 3 foot depths.

Outreach Activities

1995-1996: A field day was conducted at the field station on November 28 and December 1, 1995, and on November 21, 1996, in which the purpose of this research was explained.

1996-1997: Seven outreach activities were accomplished in which the purpose of this research was explained and demonstrated. They included 1 field day at the site (11/21/96), two poster session demonstrations (12/9/96 & 1/15/96), one conference oral presentation (12/9/96), two newspaper articles (1/15/97 & 3/1/97), and a popular magazine article.

1997-1998: Six outreach activities were accomplished in which the purpose of this research was explained. They included one field day at the site (11/11/97), two poster session demonstrations (11/18/97 & 12/2/97), two oral presentations at conferences (1/22/98 & 1/29/98), and one news feature (4/1/98).

A detailed summary of each outreach activity is presented later in this report.

Results and Discussion

Individual Field Trials: The results from each individual trial has been previously reported and discussed. Figures 1-6 show the results of preplant and postharvest soil samples for nitrate nitrogen, broccoli crop yield and individual head weight, ion exchange resin bag nitrate nitrogen, dry and sap petiole analysis, and whole plant N accumulation for the individual trials and are included for reference.

Of the four field trials conducted for this project, the 1997 Fall study had the best visual separation of fertilizer treatments as it was growing. This was substantiated over all measured parameters: broccoli head development and maturity, yield components, petiole samples for nitrate content by standard lab practices and with the in-field quick tests using fresh plant sap, postharvest soil samples, nitrate accumulation in ion exchange resin bags, and plant biomass and nitrogen content. Preplant soil samples from the field site indicated that it was extremely low in nitrogen (only 23 lbs in the top 5-feet which was undoubtedly responsible for the dramatic visual observations.

In that field trial 240 to 300 lbs N/acre brought maximum yields with good head weight. This was a higher minimum than the previous three field studies, which indicated 180 lbs. Application of preplant nitrogen was extremely important for high yields. In all trials best yields (tons per acre and weight per head) were obtained with a minimum of 60 lbs preplant. High tonnage could be obtained with lesser preplant nitrogen, but weight per head was less. Maximum yields (or close) could be obtained with any application timing of nitrogen fertilizer, all preplant (P), three split applications (PSS), two split applications (PS), or all early sidedress applications (S), providing the total amount was high enough.

A useful indicator for sufficient nitrogen application was dry petiole nitrate nitrogen. Readings of nitrate concentrations in the petiole fresh sap made with the handheld Cardy meter showed similar trends, but they were less indicative of treatment differences.

While crop yield response was not dependent upon application timing, the amount of leached nitrate, as estimated by trapping nitrate nitrogen in ion exchange resin (IER) bags was affected. Data from deep soil cores at preplant and harvest corroborated greater accumulation of nitrate deep in the profile in treatments with high nitrogen application.

By taking a systems approach to evaluate crop performance as well as soil nitrogen fates and losses, these field studies have shown that BMPs for fertilizer scheduling must consider the relative benefits of adding excess fertilizer as well as the relative costs of leaching large amounts of nitrate. The following results and discussion of the combined analysis of all trials will aim to clarify these relationships and elucidate the BMPs for broccoli production in the SJV.

Combined Field Trials: Results from the individual trials have been combined and statistically analyzed using SAS and MSTAT C. Contrasts were used to compare treatments and trials and test for significance with LSD and Fisher's protected LSD for mean separation. The contrast "names" and coefficients are:

Name	**Treatment**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**11**	**12**	**13**
	0	PSS 60	PSS 120	PSS 180	PSS 240	PSS 300	PS 60	PS 120	PS 180	P 240	S 240
PSS linear	-5	-3	-1	1	3	5	0	0	0	0	0
PSS quad	5	-1	-4	-4	-1	5	0	0	0	0	0
PS linear	-3	0	0	0	0	0	-1	1	3	0	0
PS quad	1	0	0	0	0	0	-1	-1	1	0	0
PS vs PSS	0	-1	-1	-1	0	0	1	1	1	0	0
240 (PSS v P v S)	0	0	0	0	-2	0	0	0	0	1	1
	0	0	0	0	0	0	0	0	0	-1	1

These coefficients are outlined as a visual aid to the reader to show which treatments are involved in each contrast. The linear contrast is testing for a linear response to applied N, the quadratic for a curvilinear response. For both PSS and PS linear and quadratic the check treatment (zero level of N) is included. PSS versus PS uses just the treatments with the same amounts of total applied N (60, 120, and 180 lbs). The last contrast, PSS versus P versus S, all at 240 lbs N, has 2 lines of coefficients and involves treatments 5, 12, and 13.

Contrasts were also used to compare trials (plus Fisher's protected LSD for preplant nitrogen soil samples.) One contrast compares Spring 1997 versus the 2 fall trials. The other compares Fall 1996 versus Fall 1997. Also included is the interaction of the treatment contrasts with the trial contrasts. If a treatment by trial contrast is significant, that means that the treatment comparison was not consistent over the 3 trials.

For statistical significance the following symbols apply throughout this report:

NS	not significant
*	$P \leq 0.05$
**	$P \leq 0.01$
***	$P \leq 0.001$

Some summary tables show treatment means as logs. Soil and petiole sample nitrate nitrogen data was transformed with the log to the base 10 to homogenize the variances and normalize the distributions.

Field Site Selection and Preplant Soil Samples, Table 3: Nitrate nitrogen collected in preplant soil samples were statistically different between trials (fields), however within field uniformity was fairly consistent and there was no significant difference between the treatments, nor was their an interaction between trials and treatments. The Fall 97 trial was grown in a field with the least amount of residual nitrogen compared to the Fall 96 and Spring 97 trials.

Expected Results and Outcomes, Tables 4a and 4b: The significance of the F values for the anovas (analysis of variances) and contrasts are shown in tables 4a and 4b. These tables show that trials are significantly different and that treatments are significantly different. The linear and quadratic significance for PSS and PS, along with a knowledge of the means, show that the more N applied, the more yield, the larger the heads, the more N remaining in the soil, the more N in petioles and in whole plants. These results were expected.

Primary Objectives: Determine nitrogen fertilizer BMPs. Determine if BMPs change for fall versus spring harvested broccoli. Identify nitrate movement and potential nitrate leaching losses of applied nitrogen fertilizer.

Objective Outcomes, Tables 4a and 4b: One objective of this study was to determine if applied nitrogen treatments and nitrogen BMPs might be different for spring harvested broccoli compared to fall harvested broccoli crops. *The response to increasing applied nitrogen was significantly different for spring versus fall* as evidenced by the significant contrasts for PSS linear by spring versus fall and to a lesser extent ("lesser" affected by the shorter range of values for applied N), for PS linear by spring versus fall. The differences are more obvious in the graphs of yield and head weight presented in Figures 6 and 7. *Spring yields are significantly higher than fall yields and continue to respond to additional amounts of applied fertilizer even at 300 lbs N/A.*

Another objective of this study was to determine what nitrogen fertilizer BMPs are with respect to N-rate and timing of N applications. So other contrasts of interest are PS versus PSS and the comparison of the 3 treatments with 240 lbs total applied N. These results are shown in Tables 5 and 6 for better illustration.

Table 5 shows the means averaged over the three trials for PSS (considered the BMP) and PS (averaged over the 3 trials), whether or not those are significant differences, and also the interactions with trial. The data in this table are for just the 60, 120, and 180 total lbs N applied treatments. The only significant differences between PSS and PS are for petiole N on the first sample date and whole plant N on the first 2 sample dates. There were 4 significant interactions with trial (2 for spring versus fall and 2 for fall 96 versus fall 97), but they were significant only at * or **. The main point is that *there is no difference between 1 or 2 sidedress applications of 90 lbs N/acre except in the N content of the plants early on.*

Table 6 shows the comparison of the three treatments with 240 lbs total applied N (averaged over the 3 trials). *Although there was no significant difference in yield,* there were significant differences in petiole and whole plant N early on. The sidedress (S) treatment (with no preplant applied N) had lower N in plants on the first sample date. There were also differences in soil N, except at the first 2 depths. *The 240 lbs N applied all at preplant (P) had significantly more total soil N after harvest and in the resin bags at the 3 foot depth than either the S or PSS treatments. The main point is that applying all nitrogen preplant is not a BMP because "large" pools of nitrate nitrogen are lost to the crop and remain in the soil and have potential to leach below most annual crop root zones.*

UC fertilizer recommendations in the early 1990s for broccoli production in the SJV were 100-200 lbs N/A, applied all at preplant or as split applications. These recommendations came from field experiments conducted in 1989-91 on spring and fall harvested broccoli crops and produced maximum yields of high quality broccoli crowns.

Our research determined that a preplant application of the entire amount of nitrogen needed to grow the crop is not a good BMP. Though significant amounts of applied nitrogen fertilizer are needed for maximum crop yield and head weight, no single application should exceed 90 lbs N/acre and 60 lbs N/A would be even safer to reduce the potential of nitrate moving below the crop root zone.

Table 7 continues the comparison of the three treatments with 240 lbs total applied N and shows the data for the 2 interactions that were significant at ***. For postharvest soil N at the 5-foot depth, there was a strong interaction with Fall 96 versus Fall 97. This is because the 3 240 lb N treatments were quite uniform for Fall 97 but treatment 12 (all N at preplant) had a much higher amount of N than the other treatments for Fall 96 (trial 2). Very little nitrate nitrogen was detected at the five-foot depth in 1997, even though it was the El Nino year and postharvest soil samples and IER bag removal was delayed after harvest. There were several peaks at the four-foot depth. In 1996 only the 240 preplant showed the big peak of nitrogen at the 5-foot depth, but it too had a big peak at the 4-foot depth. The important point is that *nitrate nitrogen was detected in the soil at the 4 and 5- foot depths after the crop was harvested as a result of a large preplant application of nitrogen fertilizer.*

Petiole N on the first sample date had highly significant F values for both trial contrasts. This is because treatment 13 (all N at sidedress) had the highest N in the spring but the lowest in the fall. *The first petiole sample was collected prior to the sidedress* *application. Treatment 13 should logically have the lowest N in petioles at the first date.* Then, for the 2 fall experiments, treatments 12 and 5 had very similar petiole N in 96 but treatment 12 was substantially higher than treatment 5 in 1997. *Treatment 12 should be higher than treatment 5 because the entire N is applied preplant. The important point to remember is that the first sample is collected from very small plants. There is variability among seedlings down the crop row. Sometimes plant roots are tapped into the fertilizer zone and sometimes they may still be too small or too far away from it and have not yet tapped into it.*

Secondary Objective: Is the Cardy meter a useful tool for quick test nitrate values for decision-making in broccoli nitrogen management during fall and spring growing seasons?

Petiole Nitrate nitrogen, Lab (dry tissue) versus Cardy Meter (fresh sap): In all trials nitrate determinations in fresh petiole samples were synchronized with dry petiole sampling. In each trial either two or three Cardy meters were used to gather readings from each sample. The Cardy meter data used in the analysis are the averages of the meters. Nitrate nitrogen was found in lower concentration in the fresh sap than in dry petioles at all sample dates and generally depicted the same trends discovered between treatments as the dry petiole data received from the laboratory.

In order to indicate the relative accuracy and utility of the Cardy meter as a field tool, correlations, regressions, and scatter plots were generated for lab analysis of dry petiole nitrate nitrogen versus quick sap tests with the Cardy meter petiole nitrate nitrogen. The results between dry lab samples and Cardy meter are:

Trial		r		slope	
2	Fall 1996	0.728	***	0.1492	c
3	Spr 1997	0.812	***	0.2358	a
4	Fall 1997	0.922	***	0.1651	b
combined		0.855	***	0.1597	

Although these are highly significant correlations (significantly different from zero), it would be much better to have higher correlations when correlating 2 methods of measuring the same thing. The scatter plots (not included) showed scatter.

Regressions were run with the intercept = 0, assuming that if one method has 0 N, then the other should have 0 N. Each slope is significantly different from each other slope on Fisher's Protected LSD test at P = 0.05.

The equation that describes the relationship between Cardy meter and dry lab sample petiole nitrate is: Fresh sap = 0.1597 (dry lab).

Or, if one had just a fresh sap value for ppm N and wanted the ppm N for a dry sample the equation would be: Dry lab = 6.2617 (fresh sap).

The resulting analysis of the overall large and comprehensive data set suggests that there are some pitfalls and words of caution when using the Cardy meter as a quick test for sufficient levels of nitrogen in plants growing in the field. In this research two or three Cardy meters were used for each determination and averaged. Using several meters reduces some of the variability one would encounter if relying on one Cardy meter. Secondly there is a big difference in the slopes between trials indicating that there are field specific elements that impact the Cardy meter numbers and confound the relationship to dry petiole nitrate. Moisture content and plant stress, the meters and their electrodes, and other salt constituents in the sap are possible confounding factors. Thirdly this data represents the best case scenario. Why? Because several meters were used, there was a wide range of nitrogen values in the field with treatments ranging from zero applied nitrogen to 300 lbs N/acre, more than 600 replicated determinations were considered in the correlation analysis. Normal use for a field consultant would be one meter used in many fields with average amounts of applied fertilizer. *At best the Cardy meter could accurately distinguish grossly deficient from lush nitrogen availability within the plant (field). Its utility for critical decision making would not be as reliable as information from dry petiole laboratory analysis.*

Outreach Activities 1995-1998

Educational programs such as field days, poster sessions, technical reports, demonstrations, popular articles, and meeting presentations have been used to help disseminate this information to clientele.

11/28/95 **"Broccoli Crop Field Day."** UC West Side Research and Extension Center, Five Points, CA. 20 participants: growers, PCAs, fertilizer dealers, seed company representatives.

2/20/96 **"Broccoli Season Extension Strategies."** California Farm Conference, Visalia, CA. 40 participants: small-scale vegetable growers.

10/16/96 **Poster Session**. FREP Annual Conference, Modesto, CA. 200+ participants: growers, PCAs, fertilizer dealers, etc.

11/20/96 **Poster Session**. Natural Resources Continuing Conference, Visalia, CA. 75 participants: federal and state agencies, university educators.

11/21/96 **"Cole Crop Field Day."** UC West Side Research and Extension Center, Five Points, CA. 36 participants.

12/9-11/96 **Poster Session.** UC Vegetable Crops Conference, UC Davis. 50 participants: UC Vegetable Crops Department and Cooperative Extension personnel.

1/15/97 **Nitrogen Management Newspaper Article;** CA Ag Alert Special Section: Vegetable Crops.

1/15/97 **Poster Session**. CA Plant & Soil Conference, Visalia, CA. 90 participants: growers, educators, PCAs, laboratory personnel, field researchers, & fertilizer companies, etc.

2/20/97 **Determining Nitrogen BMP for SJV Broccoli Production – Research Slide Presentation.** SJV Vegetable Crops Conference, Visalia, CA. 90 participants: growers, PCAs pesticide & fertilizer dealers.

3/1/97 **SJV Vegetable Crop Conference.** News article, Central Valley Farmer, p.1.

3/1/97 **Nitrogen Management in SJV Broccoli.** Article, Vegetable

11/11/97 **"Cole Crop Fall Field Day."** UC West Side Research & Extension Center, five Points, CA. 40 participants.

11/18/97 **Poster Session.** Fertilizer Research and Education Program Conference, Sacramento, CA.

12/1-3/97 **Poster Session.** UC Vegetable Crops Conference, UC Davis. 50 participants: UC Vegetable Crops Department and Cooperative Extension personnel.

1/22/98 **California Plant and Soil Conference, Sacramento, CA**. Research scientists. Oral presentation and conference proceedings.

1/29/98 **San Joaquin Valley Vegetable Crops Conference**, Visalia, CA. 100 participants: vegetable crops industry.

4/1/98 **Front page feature story.** Ag Alert, California Vegetables Section.