Final Report

California Department of Food and Agriculture
Fertilizer Research and Education Program

REDUCING FERTILIZER NEEDS of POTATO with NEW VARIETIES and CLONAL STRAINS of EXISTING VARIETIES

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Introduction:

Potato is one of the important vegetable crops grown in California. Potato is also one of the heaviest fertilized crops in California. An average of approximately 300 lbs. of nitrogen fertilizer per acre is applied, with rates varying from 100 to over 400 lbs/Ac. The most widely grown variety (Russet Norkotah) has a weak vine and is susceptible to early dying diseases. To compensate for these variety deficiencies, growers have increased the amount and duration of nitrogen fertilization in an effort to keep the vines alive longer and healthier. Several new clonal selections of Russet Norkotah have stronger vines and later maturity. Preliminary indications are that nitrogen fertilizer needs are lower than the standard Russet Norkotah. New red, russet and white skinned varieties are also being developed and grown that may have lower nitrogen requirements than the previous or current standard varieties.

The rates of nitrogen application on potatoes are high for several reasons: (1) Potatoes are a high value crop (approx. $4,000/Ac gross farm gate), thus the goal is maximum yield, not most efficient fertilizer use; (2) Potatoes are relatively shallow rooted and have low root density, thus are inefficient in nitrogen uptake; (3) Much of the production is on sandy soils under solid-set sprinkler irrigation, thus with high leaching potential; and, (4) A relatively new reason: the most widely grown variety (Russet Norkotah) has a weak vine and is susceptible to early dying diseases. To compensate for this last deficiency, growers have increased the amount and duration of nitrogen fertilization in an effort to keep the vines healthier and alive longer. This situation is not unique to California. Russet Norkotah is widely grown, particularly in western U.S. Thus, even a 10% reduction in fertilizer nitrogen requirement for optimum yield and quality could result in tens of thousands of tons of nitrogen that 1) growers do not have to purchase, and 2) that are not subject to leaching below the root zone and potentially contaminating runoff and ground water.

Several new clonal selections of Russet Norkotah with stronger vines and later maturity have been made. Research in other states and grower observations indicate that at least some of these clonal selections, or strains, have lower nitrogen fertilizer needs than the standard Russet Norkotah. New varieties are also being grown and/or recently released in the long white, round red, as well as russet market classes. These varieties (e.g. CalWhite, CalRed, Silverton Russet, and Klamath Russet) may also have lower nitrogen requirements. Numerous advanced selections and clones are evaluated annually. For economic and environmental reasons, these clones should be selected to produce well under conditions of relatively low input.

Objectives:

1. Determine the responses of standard and new potato varieties to nitrogen fertilization rates.
2. Determine if the new Russet Norkotah strains are more efficient in nitrogen utilization and thus require lower fertilization rates.
3. Determine if other new or potential potato varieties are more efficient in nitrogen use than existing standard varieties.
4. Demonstrate to potato industry the feasibility, profitability and sustainability of utilizing varieties/strains with lower fertilization requirements.
5. Demonstrate to potato industry the feasibility, profitability and sustainability of lower fertilization rates on standard and new varieties.

Project Description:

Nitrogen rate x variety experiments were conducted in three major production areas for three consecutive years each. The locations were Kern County growers' fields in 2000-2002, the Intermountain Research and Extension Center in Tulelake in 2000-2002, and in Stockton Delta, San Joaquin County fields in 2001-2003. In addition, a trial was conducted at the UC Davis Vegetable Crops research farm in 2000. This latter location permitted detailed whole plant sampling through out the season to monitor plant growth and nutrient uptake. A varying number and market types of varieties were included in the respective trials. Progress reports, written and oral, were presented to potato industry meetings in Kern County and Tulelake, at CDFA-FREP conferences in 2002 and 2004, and annual reports to the California Potato Research Advisory Board, CDFA, and USDA. A survey was conducted of growers in Kern, Delta and Tulelake to assess their current fertilizer practices, the bases for those practices, and the sources of information used to make decisions relative to fertilization practices. The study was conducted with support from the CDFA-FREP program, the California Potato Research Advisory Board and the USDA Potato Variety Development Program.

The three components of the FREP project are, as follows:

1. Nitrogen x Variety Trials. Ten trials were conducted in the four years of the study. Trials were conducted in Kern County and in the Tulelake Basin each of the three years, 2000 - 2002. Trials were conducted in the Stockton Delta in 2001 - 2003, and one trial was conducted at UC Davis in 2000. The number of varieties in each trial has varied from six to fifteen entries. In Kern County and at Davis, red, long white and russet varieties were studied. At Tulelake (UC-IREC) the emphasis was primarily on russets. In the Stockton Delta, the emphasis was on red skinned varieties. A total of 8 russets (four early maturing and four late maturing), 2 long whites, and 14 red varieties (nine named varieties and five numbered advanced selections) were studied. Thus, a total of 24 varieties were evaluated, some in only one location/experiment, others in as many as seven experiments at all four locations. Five nitrogen rates were utilized in each trial. An effort to have a zero (0) rate was made, but some trials were grown in grower's fields with unavoidable sprinkler applied and/or pre-plant applied nitrogen. The maximum rate varied based on the experience in the respective locations, from 300 to 400 pounds N per acre. Applications were split into two equal components at most locations, with half at planting and half as a side-dress 45-60 days after planting.

The scope and magnitude of the project grew significantly beyond the originally proposed research to CDFA-FREP. Three years of trials were conducted instead of two. In two trials, the number of varieties evaluated was 12 and 15, respectively, instead of the 8 to 10 originally planned. The total number of varieties evaluated was 24, twice what was originally planned. A third location for three years of trials, Stockton Delta, was added.

Petiole samples were accomplished at most locations at 15-day intervals. Soil samples were collected at the beginning and end of growing seasons. Whole plant samples, followed by partitioning into vines, roots and tubers, were collected at two sites at the same time as petiole samples were collected. Total nitrogen and nitrate-nitrogen, as well as P and K on some samples, were determined on all samples. Sap nitrate was not measured as originally planned due to lack of resources. Total root mass samples were also collected at maturity from two sites. The anticipated matching funds from the UC analytical laboratory for soil and plant analyses were not granted. Thus, the number of analyses was decreased.

In addition to petiole sampling throughout the season, qualitative evaluations were also accomplished for plant vigor and maturity. At harvest, tuber yields and number were measured on each plot for large, medium, small, B's, and 2's and Culls.

2. Field Days, Grower Meetings, Other Dissemination of Information. Field days were conducted at harvest in Kern County and UC-IREC locations in 2000 and 2001, at midseason at UC-IREC in 2002, and at harvest at Kern County in 2002. The annual results are published in the California Potato Research Advisory Board annual report and orally presented to the Board at their annual meetings. The FREP annual report and annual conferences were used to disseminate information. A Master of Science thesis was written and published at UC Davis. Results were presented at professional society meetings in the United States, Europe and New Zealand. Upon completion of this report, results will be published in California Agriculture, California trade magazines and journals, and professional society journal.

3. Grower Surveys. To determine and evaluate current fertilizer practices, attitudes toward changing those practices, and to determine the need for phosphorus and potassium trials, a grower survey was developed. In combination of soil and plant analyses, this survey was used to determine the need for P and K trials. The survey indicated a need for these trials, but resources were not available to conduct the research. Follow-up surveys would be required to determine the impact, if any, of this research and outreach.

Growers were randomly sampled for surveys in Kern County, Stockton Delta and Tulelake during 2000 and 2001. Slightly different surveys were used in the two years, but the information collected was similar each year. These surveys, entitled "Potato Fertility Management – 2000 Survey" and "Potato Fertility Management – 2001 Survey" are presented in the Appendix of this Report. Growers stated that they fertilized potato fields differently based on variety, cropping history and field history. Approximately half of the growers used soil tests and/or petiole analyses to establish and/or adjust fertilizer rates. Growers varied in some of their responses to the question, "What factors would make you change your potato fertilization practices?", but were in general agreement on most factors. The factors most likely to influence growers were their own fertilizer trials, new varieties with different growth habits, and soil tests / petiole analyses. Factors that were least likely to influence growers were price of fertilizer, price of potatoes, and university research trials in another state or region. Intermediate in their importance were local university research trials, whether they were in the grower's field, a neighbor's field, or university's field.

Some growers shared their soil and petiole analyses with us. We also collected soil and petiole samples from some additional fields. Some growers collect and analyze petiole samples as frequently as weekly for 7 to 10 weeks. Others sampled as infrequently as 3 times during the season. Some growers sampled areas as small as 10 acres in very large fields (e.g. >80 acres), while others analyzed a single sample from entire fields regardless of size. Those growers that used petiole analyses had different "Ideal" or "Critical" levels than the data from our studies suggest. In general, the growers' levels are 5,000 to 10,000 ppm higher during the early season and mid-season than those suggested from the research presented in this report. The amounts of nitrogen reportedly used by the growers, however, did not differ greatly from the rates suggested in our study.

Research Methods, Results and Discussion:

Table 1 lists the locations, years, nitrogen fertilizer rates, variety name, and variety market class of the ten trials. Twenty-four varieties were included at one or more sites.

Table 2 lists the specific nitrogen rates used at each of the ten sites, as well as the varieties planted. At two of the Kern County sites, significant amounts of additional nitrogen fertilizer were applied by the grower cooperator through the sprinklers. One of the Kern sites contained a large, irregular shaped area in the middle of the experiment where the top soil had been leveled / removed, exposing soil with an imbalance of nutrients that was not adequately removed with our fertilization program. At two of the Delta sites, some additional nitrogen may have been applied, but we do not have specific documentation. At one of the Tulelake locations, the site was located on in field with high residual nitrogen, high soil and water salinity and high nitrate content in the irrigation water.

Complete data collection, summarization and analyses were performed at all locations. Much of those data summaries are included as appendices in this report. However, with the numerous sites with experimental difficulties, only one year at each location was selected for complete interpretative analyses. Those four sites – 2000 Davis, 2000 Tulelake, 2001 Kern County and 2001 Stockton Delta – are the basis of most of this report, including the conclusions and recommendations.

Table 3 lists the four sites used in the data interpretative analyses and the actual nitrogen rates used. All sites included a zero (0) rate. The highest rate varied from 300 to 400 lbs/A. The increments between each of the five rates varied from 75 to 100 lbs/A.

To provide some consistency across locations and varieties, not all 24 varieties were selected for interpretative analyses. Table 4 lists the varieties used and locations at which they were grown. The list contains five russets – the late maturing Russet Burbank, early maturing Russet Norkotah, and three Russet Norkotah strains, CORN 3, TXNS 112 and TXNS 223; three reds – high vigor Red LaSoda, low vigor CalRed, and intermediate vigor Cherry Red; and high yielding, early maturing CalWhite. Russet Norkotah and its strains were included in three locations, CalRed was included in four locations, and the other entries were included in two locations.

Table 5 lists the planting and harvest dates and the dates of petiole sampling. Harvest dates varied from 111 to 140 days, the latter being due to a long in-field curing time and the former immediately after vine kill. Petiole samples were collected on four dates at two locations and on three dates at the other two sites.

Tables 6 and 7 provide soil characteristics of the experimental sites. Kern County soils are generally very sandy with very low organic matter and low cation exchange capacity. The 2001 site was slightly acid. The Davis site is a loam soil with low organic matter, twice the total nitrogen content of Kern County but still low. The cation exchange capacity is also approximately twice that of the Kern sites. Tulelake is a silty clay loam with relatively high organic matter content (approximately 10X the total N content of Kern County) and a high cation exchange capacity. Both the Davis and Tulelake sites were slightly alkaline.

Table 1. List of locations, years and varieties included in the potato nitrogen fertilization x variety x location study

Entry	Davis	Delta			IREC			Kern		
	2000	2001	2002	2003	2000	2001	2002	2000	2001	2002
Russet Burbank	X				X	X	X			
Gem Russet					X	X				
Klamath Russet					X	X	X			
Silverton Russet					X			X	X	X
Russet Norkotah	X				X	X	X	X	X	X
CORN3	X				X	X	X	X	X	X
TXNS112	X				X	X	X	X	X	X
TXNS223	X				X		X	X	X	X
RedLaSoda	X			X				X	X	X
CalRed	X	X	X		X			X	X	X
Cherry Red	X							X	X	X
Chieftain		X	X	X						
Red Ruby		X								
Durango									X	X
Mazama		X	X						X	X
Winema		X	X						X	X
Modoc		X	X							X
CO89097-2R				X						
NDC5281-2R				X						
NDO4323-2R		X	X							
NDTX4271-5R				X						X
NDTX4304-1R				X						X
CalWhite	X	X						X	X	X
A91556-2W		X								

Table 2. Nitrogen rates and varieties used at each of the ten experimental sites.

Table 2a. Kern County

Kern Co.									
	2000			2001			2002		
Treatment	N Rates	Entry	Type	N Rates	Entry	Type	N Rates	Entry	Type
		Russet Norkotah	RU		Russet Norkotah	RU		Russet Norkotah	RU
F1	125	TXNS 112	RU	0	CORN 3	RU	115	CORN 3	RU
F2	165	TXNS 223	RU	80	TXNS 112	RU	179	TXNS 112	RU
F3	205	CORN #3	RU	160	TXNS 223	RU	243	TXNS 223	RU
F4	245	Silverton	RU	240	Silverton	RU	307	Silverton	RU
F5	285	Red LaSoda	R	320	Red LaSoda	R	371	CalWhite	W
		CalRed	R		CalWhite	W		Red LaSoda	R
		Cherry Red	R		CalRed	R		CalRed	R
		CalWhite	W		Cherry Red	R		Cherry Red	R
					Winema	R		Mazama	R
					Mazama	R		Winema	R
					Durango	R		Durango	R
								Modoc	R
								NDTX4271-5	R
								NDTX4304-1	R

Table 2b. Tulelake

IREC									
	2000			2001			2002		
Treatment	N Rates	Entry	Type	N Rates	Entry	Type	N Rates	Entry	Type
		Russet Norkotah	RU		Russet Norkotah	RU		Russet Norkotah	RU
F1	0	CORN #3	RU	0	CORN #3	RU	0	Burbank	RU
F2	100	TXNS 112	RU	100	TXNS 112	RU	80	CORN #3	RU
F3	200	TXNS 223	RU	200	Russet Burbank	RU	160	TXNS 112	RU
F4	300	Russet Burbank	RU	300	Gem Russet	RU	240	Klamath	RU
F5	400	Gem Russet	RU	400	Klamath Russet	RU	320	TXNS 223	RU
		Silverton Russet	RU						
		Klamath Russet	RU						
		CalRed	R						

Table 2c. Stockton Delta

Delta									
	2001			2002			2003		
Treatment	N Rates	Entry	Type	N Rates	Entry	Type	N Rates	Entry	Type
		Chieftan	R		Chieftan	R		Chieftain	R
F1	0	Cal Red	R	0	Cal Red	R	0	Red LaSoda	R
F2	80	Modoc	R	80	Mazama	R	80	CO89097-2	R
F3	160	NDO4323--2	R	160	Winema	R	160	NDC5281-2	R
F4	240	Red Ruby	R	240	Modoc	R	240	NDTX4271-5	R
F5	320	Cal White	W	320	NDO4323--2	R	320	NDTX4304-1	R
		A91556-2W	W						

Table 2d. Davis

Davis			
2000			
Treatment	N Rates	Entry	Type
		Russet Norkotah	RU
F1	0	CORN #3	RU
F2	75	TXNS 112	RU
F3	150	TXNS 223	RU
F4	225	Russet Burbank	RU
F5	300	Red LaSoda	R
		CalRed	R
		Cherry Red	R
		CalWhite	W

Table 3. Rates of Applied Nitrogen at the Four Locations Used for Interpretative Analyses.

Applied Nitrogen Rates for California Locations				
Treatment	Kern Co. 2001	Davis 2000	Stockton Delta 2001	IREC 2000
1	0	0	0	0
2	80	75	80	100
3	160	150	160	200
4	240	225	240	300
5	320	300	320	400

Table 4. Varieties used for impetrative analyses and the locations grown.

Variety	Davis 2000	Delta 2001	IREC 2000	Kern 2001
Russet Burbank	X		X	
Russet Norkotah	X		X	X
CORN 3	X		X	X
TXNS 112	X		X	X
TXNS 223	X		X	X
Red LaSoda	X			X
CalRed	X	X	X	X
Cherry Red	X			X
CalWhite	X	X		X

Table 5. Dates of Petiole Sampling at Four Locations

Davis 2000		IREC 2000		Kern Co 2001		Stockton Delta 2001	
Planted: 3/24		Planted: 5/10		Planted: 2/5		Plamted: 5/30	
Sample	DAP	Sample	DAP	Sample	DAP	Sample	DAP
Pet1	---	Pet1	---	Pet1	---	Pet1	47
Pet2	56	Pet2	---	Pet2	59	Pet2	---
Pet3	70	Pet3	65	Pet3	74	Pet3	62
Pet4	84	Pet4	85	Pet4	89	Pet4	77
Pet5	98	Pet5	106	Pet5	107	Pet5	---
Harvest	111	Harvest	140	Harvest	136	Harvest	118

Table 6. Soil characteristics of research sites

Table 6.1: Kern 2001 soil salinity and physio-chemical characteristics.

Timing	N rate	Soil depth	pH	Electrical conductivity	Cation exchange capacity	Organic matter
	kg·ha⁻¹	*cm*		*dS·m⁻¹*	*cmol·kg⁻¹*	*g·kg⁻¹*
Pre-plant		0-23	6.3	2.7	13.1	3.6
		23-46	6.4	1.6	12.5	2.8
Harvest[z]	0	0-30	6.4	1.3		
	0	30-53	6.3	1.3		
	0	53-76	6.8	1.3		
	180	0-30	6.0	1.8		
	180	30-53	5.9	1.5		
	180	53-76	6.5	1.6		
	360	0-30	5.4	2.3		
	360	30-53	5.8	1.6		
	360	53-76	6.4	1.4		

[z] Means were averaged across Russet Norkotah, TXNS 112, and CalRed **1**

Table 6.2: Kern 2001 soil fertility characteristics.

Timing	N rate	Soil depth	Soil fertility							
			TOT-N	NH_4-N	NO_3-N	Olsen-P	X-K	X-Ca	X-Mg	X-Na
	kg·ha⁻¹	*cm*	*g·kg⁻¹*	*mg·kg⁻¹*		*mg·kg⁻¹*	*cmol·kg⁻¹*			
Pre-plant		0-23	0.40	5.5	4.2	70.0	0.3	4.0	0.8	0.2
		23-46	0.30	4.9	6.0	67.2	0.2	3.5	0.8	0.2
Harvest[z]	0	0-30	0.40	2.0	2.3					
	0	30-53	0.43	1.7	1.7					
	0	53-76	0.40	1.6	1.5					
	180	0-30	0.40	4.5	4.7					
	180	30-53	0.40	2.3	3.2					
	180	53-76	0.40	1.9	4.0					
	360	0-30	0.42	16.7	15.3					
	360	30-53	0.40	4.2	6.7					
	360	53-76	0.40	2.1	4.7					

[z] Means were averaged across Russet Norkotah, TXNS 112, and CalRed

Table 6.3: Davis 2000 soil salinity and physio-chemical characteristics.

Timing	Soil depth	pH	Electrical conductivity	Cation exchange capacity
	cm		*dS·m^{-1}*	*cmol·kg^{-1}*
Pre-plant	0-23	7.4	0.2	27.6
	23-46	7.6	0.2	31.4

Table 6.4: Davis 2000 soil fertility characteristics.

		Soil	Soil fertility						
Timing	N rate	depth	TOT-N	NH_4-N	NO_3-N	Olsen-P	X-K	X-Ca	X-Mg
	kg·ha^{-1}	*cm*	*g·kg^{-1}*	*mg·kg^{-1}*		*mg·kg^{-1}*	*cmol·kg^{-1}*		
Pre-plant		0-23	0.82			18.7	0.5	6.5	10.0
		23-46	0.67			8.5	0.3	6.7	10.3
Harvest	0	0-23	0.80	3.0	3.9				
	0	23-46	0.60	2.7	2.1				
	84	0-23	0.70	2.8	3.6				
	84	23-46	0.60	2.1	1.9				
	168	0-23	0.80	3.2	6.1				
	168	23-46	0.70	2.8	5.4				
	252	0-23	0.80	3.4	4.3				
	252	23-46	0.60	2.8	3.2				
	336	0-23	0.80	3.4	8.2				
	336	23-46	0.60	2.8	5.9				

Table 6.5: Tulelake 2000 soil salinity and physio-chemical characteristics.

Timing	N rate	Soil depth	pH	Electrical conductivity	Cation exchange capacity	Organic matter
	kg·ha^{-1}	*cm*		*dS·m^{-1}*	*cmol·kg^{-1}*	*g·kg^{-1}*
Pre-plant		0-20	7.2	1.0	48.1	65.1
Harvest	0	0-20	7.4	0.6		
	0	20-40	7.5	0.7		
	112	0-20	7.4	0.8		
	112	20-40	7.5	0.9		
	224	0-20	7.3	1.0		
	224	20-40	7.4	1.2		
	336	0-20	7.2	1.7		
	336	20-40	7.3	1.8		
	448	0-20	6.8	1.7		
	448	20-40	7.1	1.5		

Table 6.6: Tulelake 2000 soil fertility characteristics.

		Soil	Soil fertility						
Timing	N rate	depth	TOT-N	NH_4-N	NO_3-N	Olsen-P	X-K	X-Ca	X-Mg
	kg·ha^{-1}	*cm*	*g·kg^{-1}*	*mg·kg^{-1}*		*mg·kg^{-1}*	*cmol·kg^{-1}*		
Pre-plant		0-20	4.7	12.2	43.8	29.4	2.3	30.5	7.5
Harvest	0	0-20	4.5	8.2	15.2				
	0	20-40	4.0	7.1	12.0				
	112	0-20	4.3	7.8	15.3				
	112	20-40	3.8	9.2	12.5				
	224	0-20	4.3	9.0	15.4				
	224	20-40	3.9	7.9	14.4				
	336	0-20	4.2	9.6	30.4				
	336	20-40	3.9	7.2	33.2				
	448	0-20	4.4	9.1	26.5				
	448	20-40	4.0	8.1	31.2				

Table 7. Pre-plant soil total nitrogen (i.e. OM) and residual nitrate and ammonium nitrogen after harvest.

2000 Davis Soil Fertility						
Treatment Sampled	**Total N (%)**		**NH_4-N (ppm)**		**NO_3-N (ppm)**	
	0-9"	**9-18"**	**0-9"**	**9-18"**	**0-9"**	**9-18"**
Pre-plant	0.082	0.067	--	--	--	--
0 N	0.080	0.060	3.0	2.7	3.9	2.1
75 N	0.070	0.060	2.8	2.1	3.6	1.9
150 N	0.080	0.070	3.2	2.8	6.1	5.4
225 N	0.080	0.060	3.4	2.8	4.3	3.2
300 N	0.080	0.060	3.4	2.8	8.2	5.9

2000 IREC Soil Fertility						
Treatment Sampled	**Total N (%)**		**NH_4-N (ppm)**		**NO_3-N (ppm)**	
	0-9"	**9-18"**	**0-9"**	**9-18"**	**0-9"**	**9-18"**
Pre-plant	0.47		12.2		43.8	
0 N	0.45	0.40	8.2	7.1	15.2	12.0
100 N	0.43	0.38	7.8	9.2	15.3	12.5
200 N	0.43	0.39	9.0	7.9	15.4	14.4
300 N	0.42	0.39	9.6	7.2	30.4	33.2
400 N	0.44	0.40	9.1	8.1	26.5	31.2

2001 Kern Co. Soil Fertility									
Treatment Sampled	**Total N (%)**			**NH_4-N (ppm)**			**NO_3-N (ppm)**		
	0-12"	**12"-21"**	**21"-30"**	**0-12"**	**12"-21"**	**21"-30"**	**0-12"**	**12"-21"**	**21"-30"**
Pre-plant	0.040	0.030	--	**5.5**	**4.9**	**--**	**4.2**	**6.0**	**--**
0 N	0.040	0.043	0.040	**2.0**	**1.7**	**1.6**	**2.3**	**1.7**	**1.5**
160 N	0.040	0.040	0.040	**4.5**	**2.3**	**1.9**	**4.7**	**3.2**	**4.0**
320 N	0.042	0.040	0.040	**16.7**	**4.2**	**2.1**	**15.3**	**6.7**	**4.7**

Yield responses to nitrogen fertilization.

Figures 1a – 1d illustrate the yield responses to fertilizer nitrogen at the Kern 2001 location. This very sandy location was very responsive to nitrogen, with the maximum yield not reached with 320lbs/A nitrogen fertilizer for many varieties. This was true for Russet Norkotah and the 3 strains, Red LaSoda and CalWhite. However, the red varieties with lower yielding potential – CalRed, Cherry Red, Winema, Mazama and Durango – and the early russet variety Silverton Russet reached maximum yield at lower nitrogen rates. While Russet Norkotah and the three Russet Norkotah strains continued to be responsive to nitrogen at higher rates, the CORN 3 strain and Silverton Russet were significantly more efficient at lower rates of N. Silverton Russet had a higher yield at 80 lbs/A than the Russet Norkotah lines, but did not increase yield as much at higher rates as the other russets. The highest yields were harvested from CalWhite and Red LaSoda. Both were very responsive to increasing nitrogen content.

The Kern 2000 trial received an additional 125 lbs of nitrogen per acre from grower-applied fertigation. Thus, the lowest rate of nitrogen was 125 lbs/A. On average, the yields increased up to the third rate, 205 lbs/A, and then remained at that level. Russet Norkotah and the RN strains did not all respond the same. Russet Norkotah reached its highest yield at the fourth rate, 245 lbs/A, and decreased at the highest rate. CORN 3 reached its highest yield at the second rate, 165 lbs/A, and decreased slightly at higher rates. TXNS 112 and TXNS 223 reached maximum yields at the third rate, 205 lbs/A. Silverton Russet, another early maturing russet, continued to respond to increasing nitrogen, even at the highest rate. Red LaSoda and CalRed, the first a high yielding red and the second a low yielding red, both reach their respective highest yield at the second rate, 165 lbs/A. They both decreased in yield slightly at increasing rates. Cherry Red had its highest yield at the fourth rate, 245 lbs/A, and decreased at the highest nitrogen rate. CalWhite, an early maturity and high yielding white, as it did in 2001, continued to respond to nitrogen at all applied rates.

Figures 2a and 2b illustrate the yield responses to fertilizer nitrogen at the Davis 2000 location. This sandy loam soil had been depleted of residual nitrogen in the previous crop, thus the response to nitrogen was curvilinear. Yields of all varieties was low with no applied fertilizer, increased sharply up to the fourth rate, 225 lbs/A and then decreased significantly at the highest rate, 300 lbs/A. This pattern was generally true for all varieties. Red LaSoda and Cherry Red, however, reached their maximum yields at the third rate, 150 lbs/A, and decreased with subsequent nitrogen increments. The responses among Russet Norkotah and the RN strains were nearly identical. CORN 3 was the highest yielding variety at all levels of nitrogen.

Figures 3a and 3b illustrate the yield responses to fertilizer nitrogen at the Tulelake IREC 2000 location. This silty clay loam soil site with high organic matter had the highest yields of any site, with an average yield of over 400 cwt/A at the zero rate. The IREC 2000 trial produced not only the highest yields of all the trials, but also the highest yield of No. 2's and Cull tubers. Thus, for most trials, the responses were the same for total yield as for U.S. No. 1 or Marketable yield. Yields, averaged across all varieties, increased significantly to the third rate, 200 lbs/A. Yields continued to increase at the higher rates, in contrast to the Kern and Davis sites, but at insignificant amounts. When only the U.S. No. 1 marketable tubers were considered, the second rate, 100 lbs/A, resulted in yields equal to the higher rates. Again, in contrast to the Kern and Davis sites, yields did not decrease at higher fertilization rates. Not all varieties responded the same, however. As observed by growers, and as suggested by research in other states, Russet

Norkotah continued to respond at highest rates of nitrogen, while CORN 3 did not. CORN 3 reached its maximum yield of U.S. No. 1's at the second rate, 100 lbs/A, and decreased at higher rates. TXNS 223 responded similarly to Russet Norkotah. TXNS 112 increased in yield up to the fourth rate and then decreased. Russet Burbank reached maximum yield at the third rate, 300 lbs/A, and then decreased slightly. Gem Russet increased yield up to the fourth rate, 300 lbs/A, and then decreased. Silverton Russet, an early maturing variety, reached its maximum yield at the third rate, 200 lbs/A, and then slightly decreased at higher rates. Klamath Russet, a late maturing variety, responded very similarly to Silverton Russet. CalRed, a medium maturity red skinned variety that produces large numbers of small tubers, reached maximum yield at the third rate, 300 lbs/A, and then decreased slightly.

The 2001 trial at Tulelake was located on the old IREC headquarters field, which had high residual soil nitrogen and high salt. The results are illustrated in the Appendix. The 2002 trial at Tulelake was located on the new lands of the IREC headquarters field. The results are not discussed in detail here, and like 2001, are presented in the Appendix. However, the results were similar to those in 2000. On average, yields increased up to the third rate, 160 lbs/A, and then decreased. Russet Norkotah and the three strains all responded similarly. Russet Burbank responded slightly differently; maximum yield was achieved at the second rate, 80 lbs/A, but did not decrease at the higher rates. Klamath Russet responded similarly to the Russet Norkotah entries.

Figures 4a and 4b illustrate the yield responses to fertilizer nitrogen at the Stockton Delta 20001 location. This organic soil site, as expected, did not respond, on average, to additional fertilizer beyond the second rate, 80 lbs/A. Yields did not decrease at higher rates, however, and the yield of large and medium size tubers increased slightly up to the fourth rate, 240 lbs/A. Not all varieties responded the same. The highest yielding entry, Chieftain, had its highest yield at the second rate, 80 lbs/A. The two lowest yielding entries were CalRed and A91556-1W, a late maturing long white. CalRed responded similarly to Chieftain, while A91556-1W did not respond significantly to any additional nitrogen. Modoc and NDO4323-2R, both early maturing reds, continued to respond to increasing nitrogen at all rates. Red Ruby, a medium maturing red, responded similarly to Modoc and NDO4323-2R. CalWhite, an early maturing long white, with yields similar to Chieftain, reached its highest yield at the third rate, 160 lbs/A, and decreased slightly in total yield as rates increased beyond the optimum. The No. 1 yields did not decrease at higher rates, however.

The 2002 Stockton Delta trial received an unknown quantity of additional nitrogen from grower-applied fertigation. No yield responses were measured; in some cases, e.g. Chieftain, the yields decreased at higher rates. The results are illustrated in the Appendix. The 2003 Stockton Delta trial was confounded with heavy weed infestation and subsequent high experimental error. Thus, analysis of this trial was difficult. The results are illustrated in the Appendix.

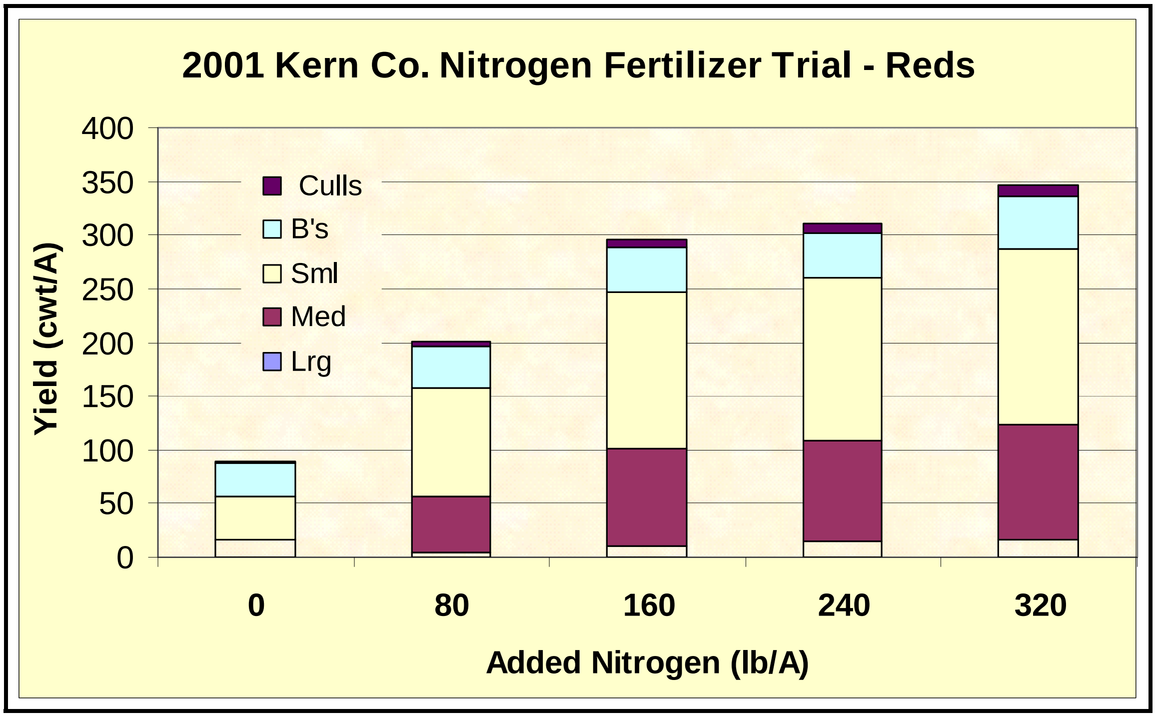

Figure 1a. Response to Nitrogen Fertilizer in Kern County 2001, Average of all Varieties

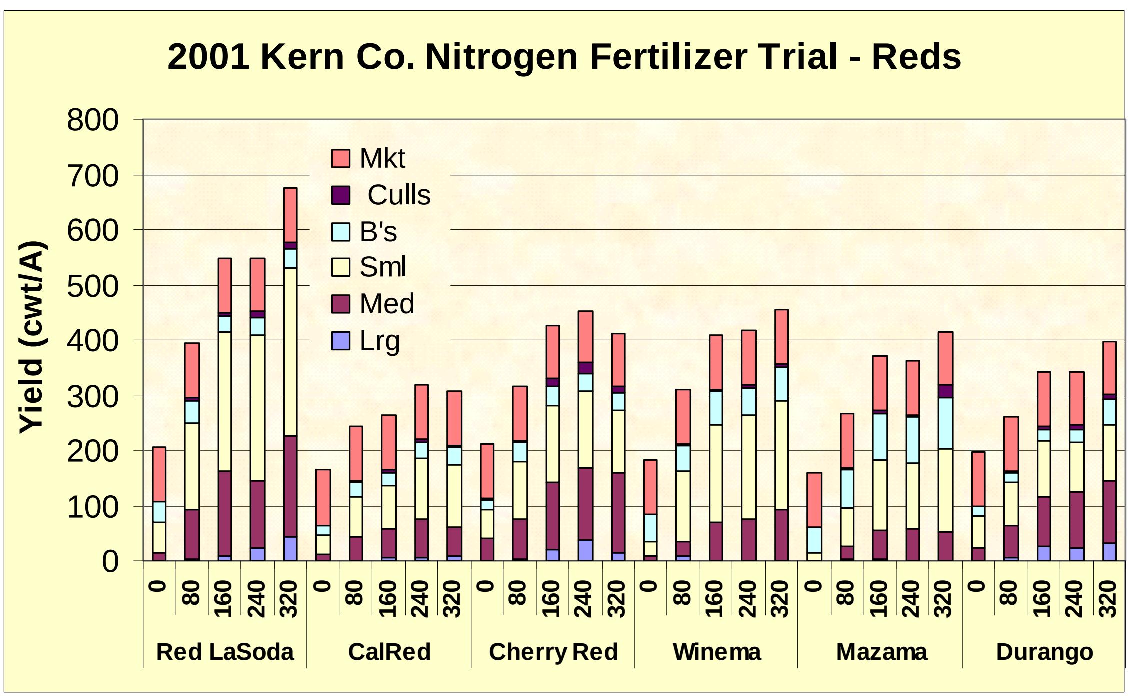

Figure 1b. Response to Nitrogen Fertilizer in Kern County 2001 of Red Skinned Varieties

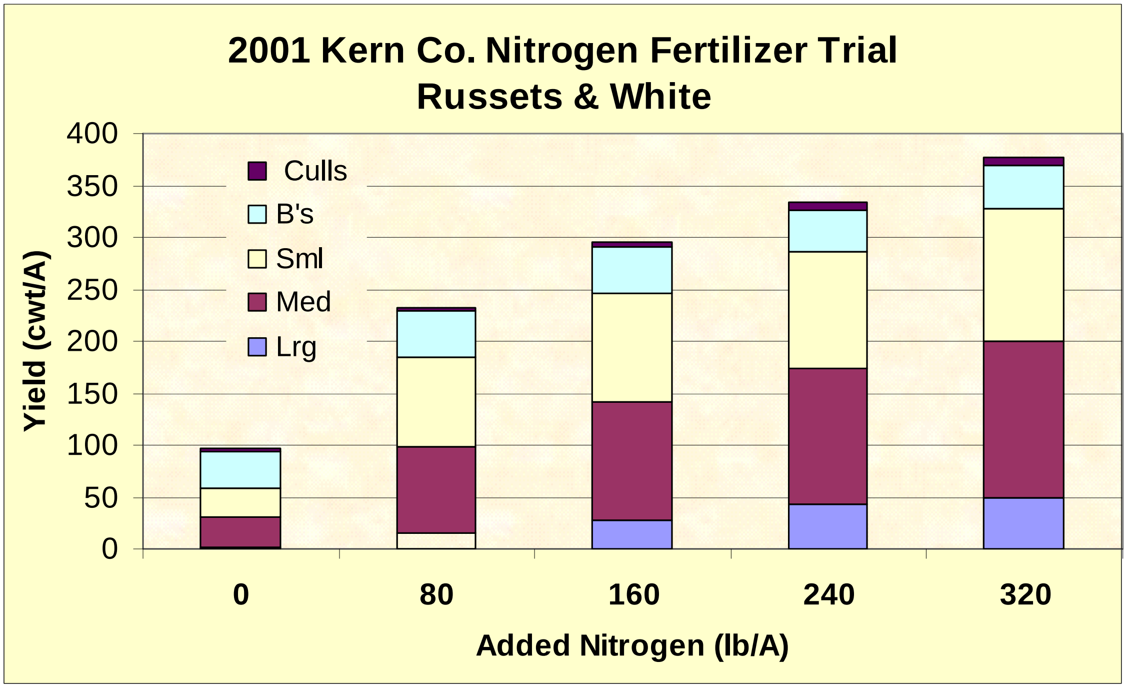

Figure 1c. Response to Nitrogen Fertilizer in Kern County 2001, Average of Russet and Long White Varieties

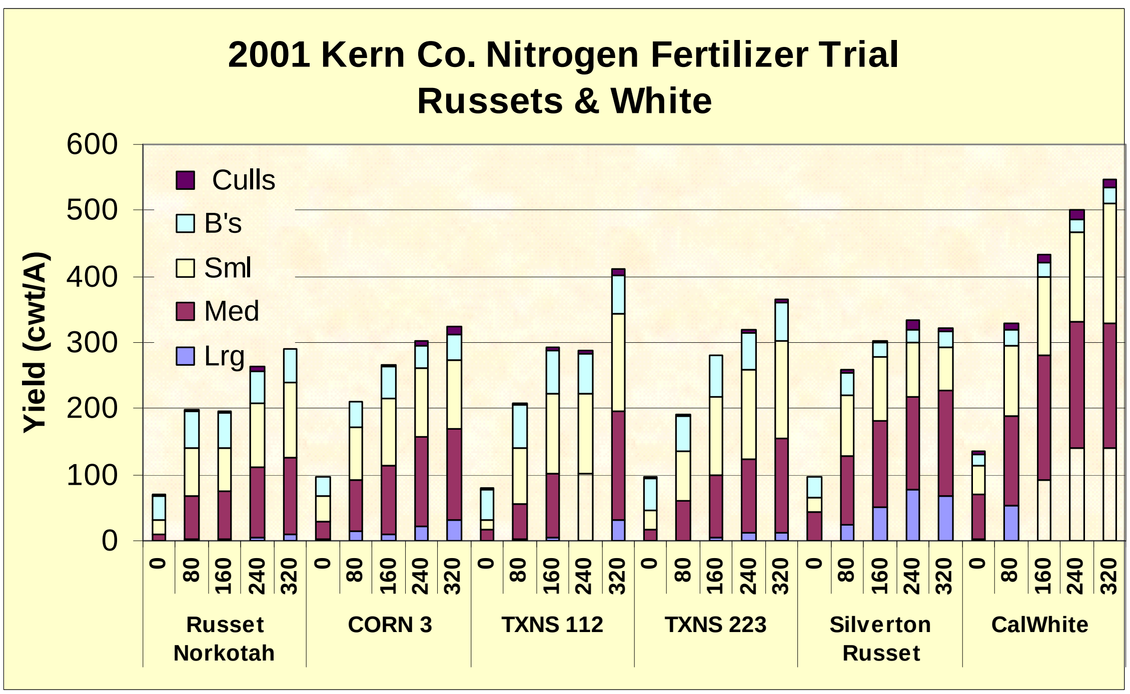

Figure 1d. Response to Nitrogen Fertilizer in Kern County 2001 of Russet and Long White Varieties

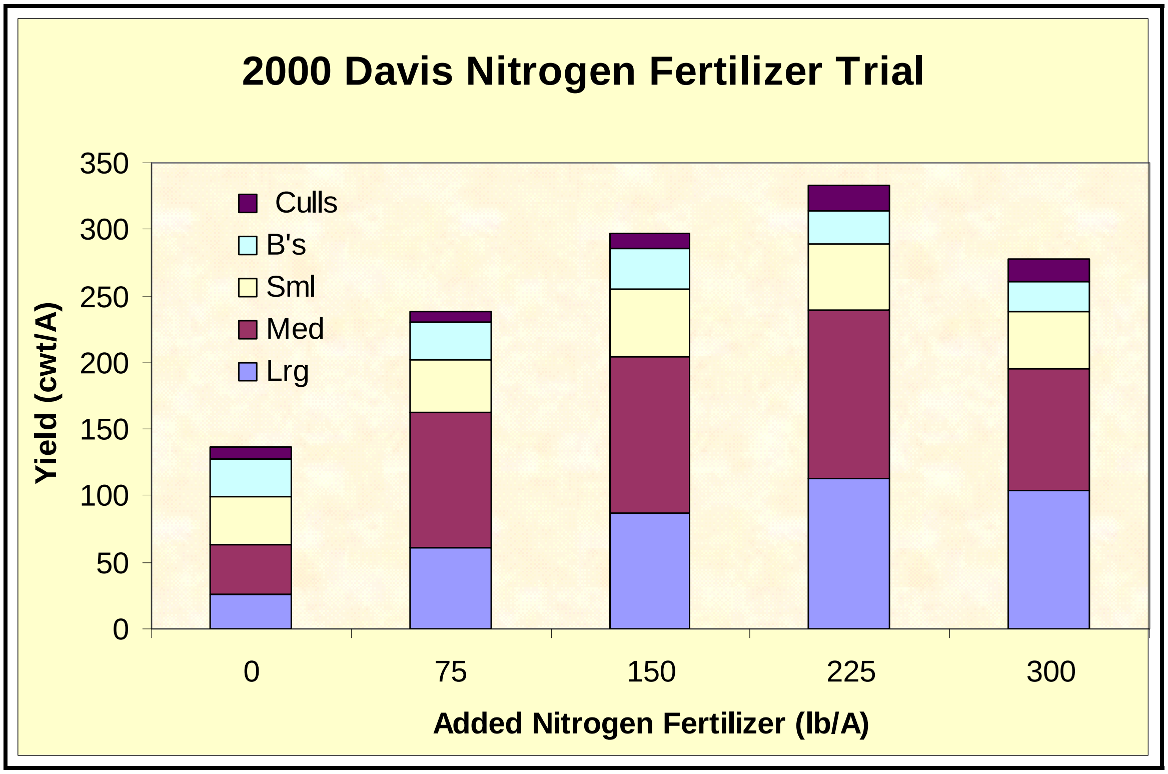

Figure 2a. Response to Nitrogen Fertilizer at Davis 2000, Average of all Varieties

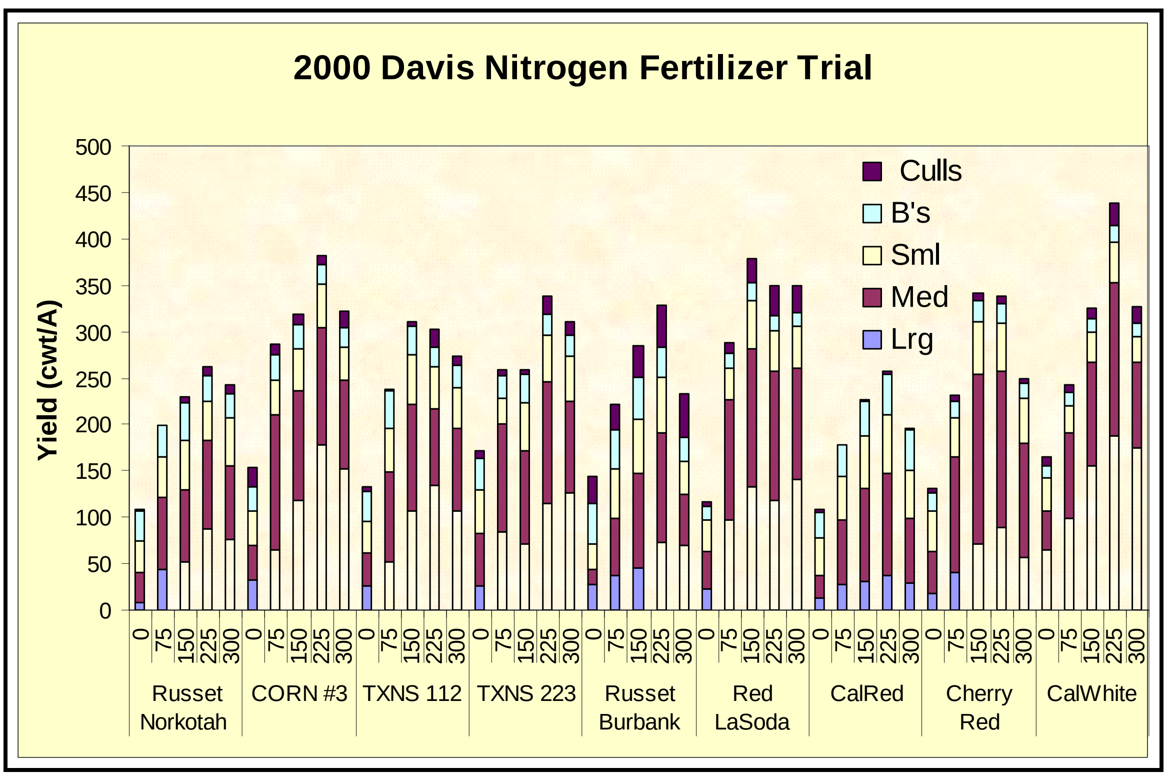

Figure 2b. Response to Nitrogen Fertilizer at Davis 2000 of all Varieties

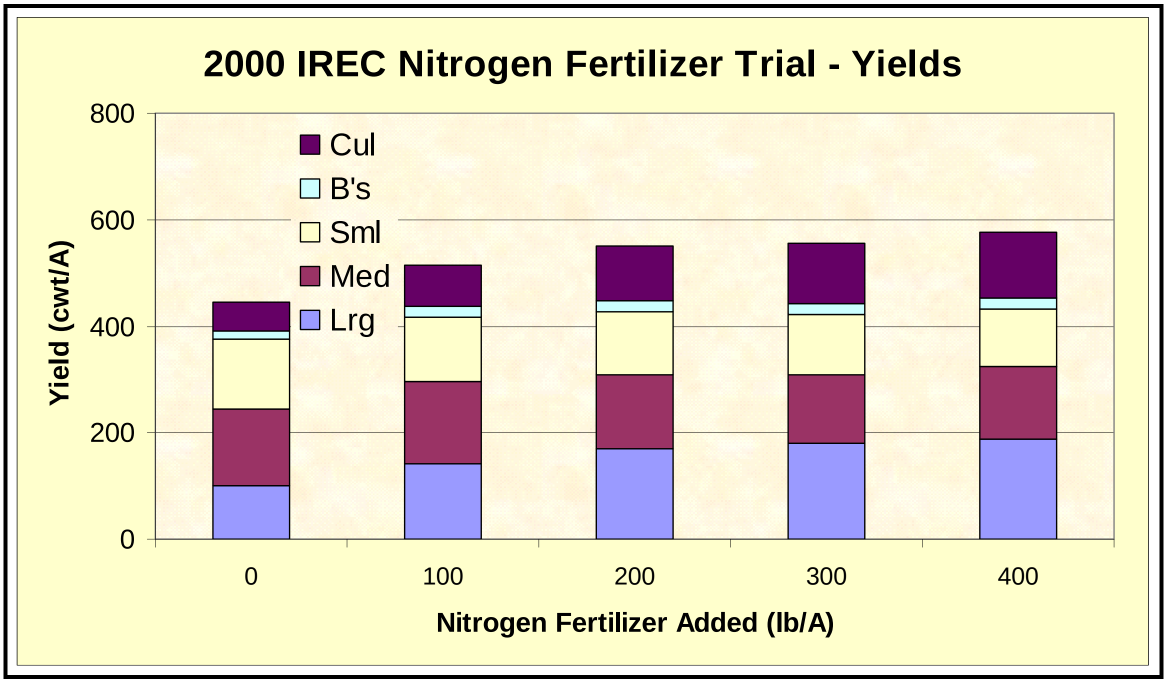

Figure 3a. Response to Nitrogen Fertilizer at Tulelake 2000, Average of all Varieties

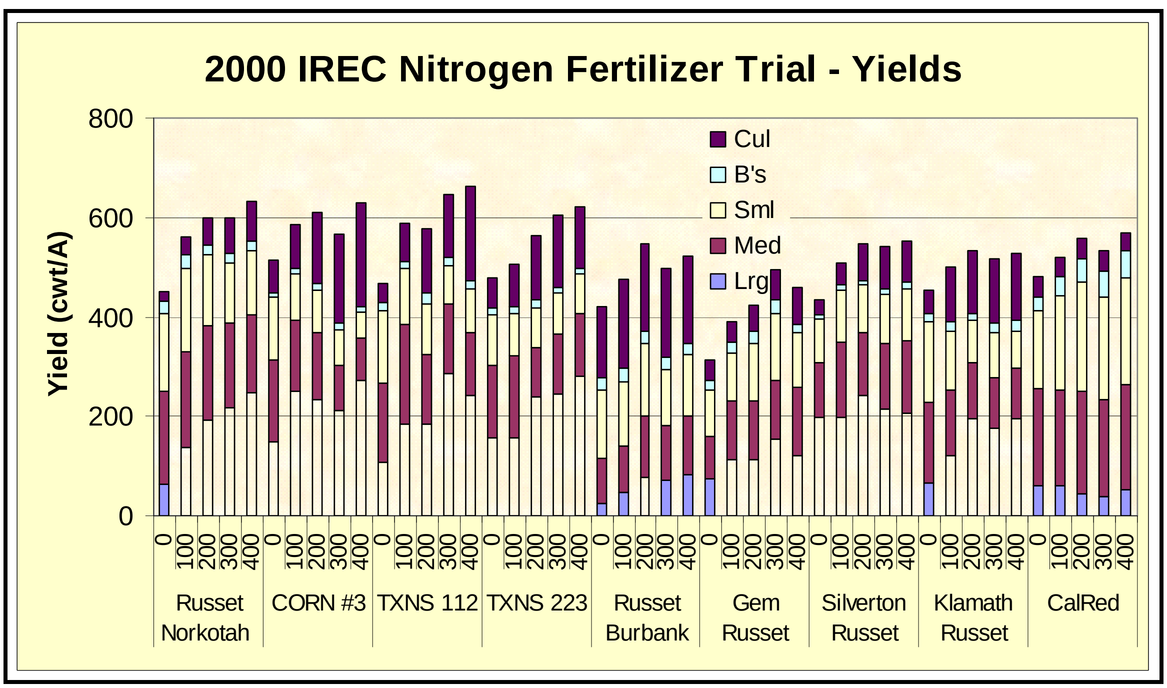

Figure 3b. Response to Nitrogen Fertilizer at Tulelake 2000 of all Varieties

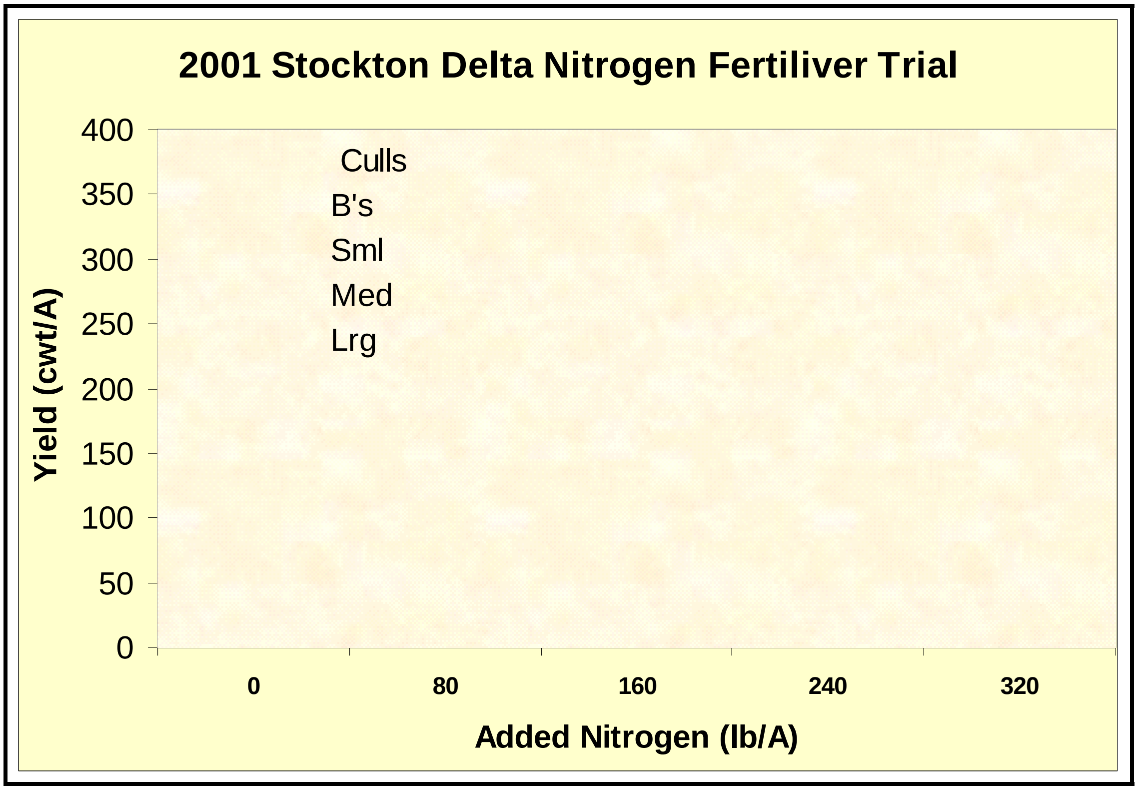

Figure 4a. Response to Nitrogen Fertilizer in Stockton Delta 2001, Average of all Varieties

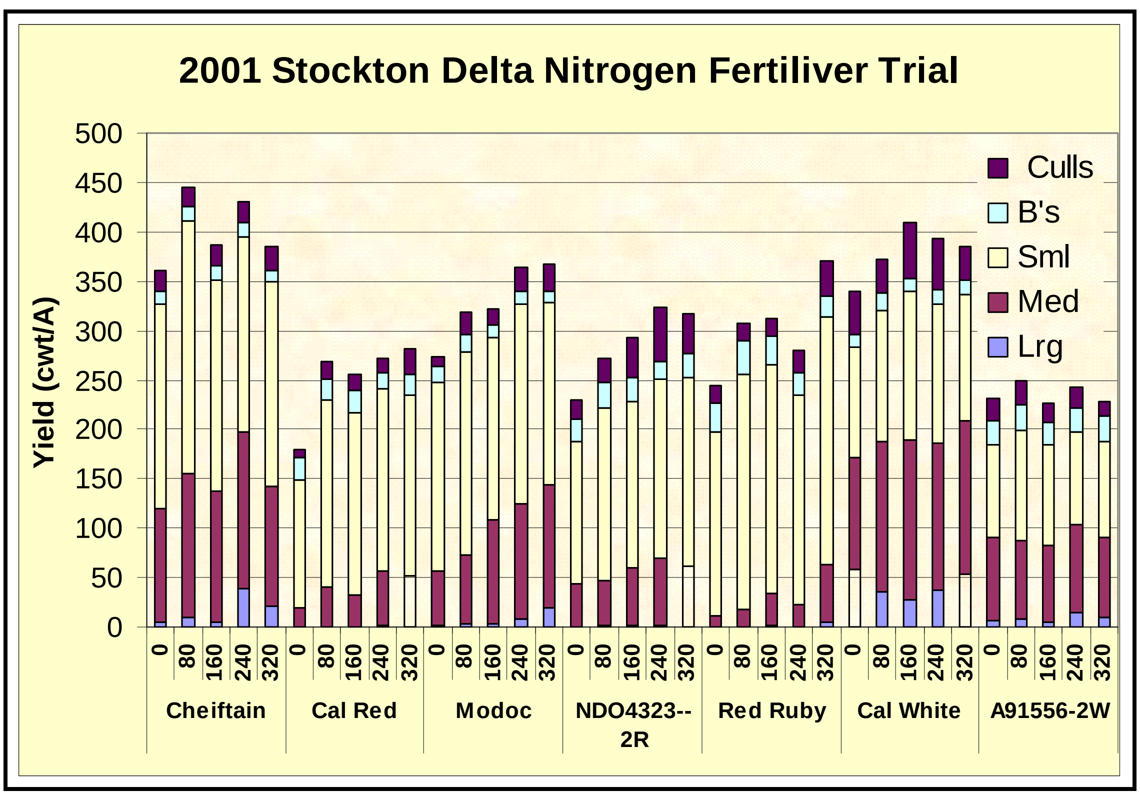

Figure 4b. Response to Nitrogen Fertilizer in Stockton Delta 2001 of all Varieties

General relationships among nitrogen treatments, yield, petiole nitrate concentration, and other parameters

Tables 8 – 11 show the general and simple relationships among the nitrogen treatments and the measured parameters of early season plant vigor, mid-season plant vigor, vine maturity, total yield, and petiole nitrate levels at the sequential sampling times.

Table 8 is the correlation matrix for Kern County 2001. It indicates that the nitrogen fertilizer rate is highly correlated with yield, plant vigor, and petiole nitrate concentrations at all sampling dates. Nitrogen rate was not related to maturity, a parameter that is much more influenced by variety. This correlation matrix also indicates that the first petiole sampling date had the highest correlation with yield, and the correlation decreased with time.

Table 9 is the correlation matrix for Davis 2000. It indicates an even higher correlation between nitrogen treatment and yield and nitrogen treatment and the respective petiole nitrate concentrations. As with Kern County, the highest correlation between yield and petiole content occurred at the first sampling date and decreasing with time.

Table 10 is the correlation matrix for Tulelake 2001. The correlations were very similar to those at Kern County and Davis. In contrast to Kern County, mid-season vigor was related to nitrogen treatment. Again, yield was most highly correlated with early season petiole nitrate concentration.

Table 11 is the correlation matrix for the Stockton Delta 2001. It shows a significant correlation between nitrogen treatment and yield but not as high as Kern County, Tulelake or Davis. Similarly, the correlations between nitrogen treatment and petiole nitrogen concentration were not as high. Furthermore, the correlation between and yield were lower than at the other locations and increased throughout the season instead of decreasing.

Table 12 is the correlation matrix for all four locations. This indicates the same relationships as the four individual location correlation matrices. The nitrate petiole concentration at the first sampling is the best predictor of relative yield and plant vigor.

Table 13 summarizes the correlations between yield and petiole nitrate concentrations at the four locations at each of the respective sampling dates. At the Kern, Davis and Tulelake locations, the highest correlation was at the earliest sampling date, and at all three locations, the correlation was approximately 0.50. The corresponding value in the Delta was only 0.23. Figure 5a illustrates the correlations over time at each location. Figure 5b illustrates the average correlation of all locations and with the three similar locations.

Table 8. Correlation Matrix, Kern County 2001, showing relationships among treatments and measured parameters, and respective statistical significance

	Trt	Yld	Vig1	Vig2	Mat	NTtl	NO1	NO2	NO3	NO4
Trt	1.00	0.68 <.0001	0.58 <.0001	0.67 <.0001	-0.12 0.0285	0.69 <.0001	0.78 <.0001	0.75 <.0001	0.69 <.0001	0.64 <.0001
Yld		1.00	0.75 <.0001	0.76 <.0001	-0.10 0.07	0.88 <.0001	0.50 <.0001	0.35 <.0001	0.32 <.0001	0.15 0.06
Vig1			1.00	0.73 <.0001	-0.27 <.0001	0.69 <.0001	0.46 <.0001	0.27 0.0002	0.30 <.0001	0.12 0.11
Vig2				1.00	-0.22 0.0001	0.78 <.0001	0.55 <.0001	0.42 <.0001	0.36 <.0001	0.19 0.01
Mat					1.00	-0.33 0.003	-0.09 0.25	0.11 0.15	-0.03 0.72	0.05 0.55
NTtl						1.00	0.54 <.0001	0.46 0.002	0.43 0.003	0.20 0.21
NO1							1.00	0.53 0.0003	0.64 <.0001	0.49 0.001
NO2								1.00	0.74 <.0001	0.77 <.0001
NO3									1.00	0.81 <.0001
NO4										1.00

Table 9. Correlation Matrix, Davis 2000, showing relationships among treatments and measured parameters, and respective statistical significance

	Trt	Yld	Vig1	NTtl	NO1	NO2	NO3	NO4
Trt	1.00	0.59 <.0001	0.57 <.0001	0.59 <.0001	0.89 <.0001	0.84 <.0001	0.84 <.0001	0.83 <.0001
Yld		1.00	0.65 <.0001	1.00 <.0001	0.50 <.0001	0.40 <.0001	0.39 <.0001	0.30 0.0001
Vig1			1.00	0.65 <.0001	0.57 <.0001	0.49 <.0001	0.53 <.0001	0.38 <.0001
NTtl				1.00	0.50 <.0001	0.40 <.0001	0.39 <.0001	0.30 0.0001
NO1					1.00	0.91 <.0001	0.89 <.0001	0.86 <.0001
NO2						1.00	0.86 <.0001	0.88 <.0001
NO3							1.00	0.84 <.0001
NO4								1.00

Table 10. Correlation Matrix, Tulelake IREC 2000, showing relationships among treatments and measured parameters, and respective statistical significance

	Trt	Yld	Vig1	Vig2	Mat	NTtl	NO1	NO2	NO3
Trt	1.00	0.58 <.0001	0.16 0.12	0.53 <.0001	0.14 0.17	0.10 0.30	0.81 <.0001	0.89 <.0001	0.19 0.06
Yld		1.00	0.60 <.0001	0.45 <.0001	0.05 0.62	-0.01 0.93	0.52 <.0001	0.43 <.0001	0.13 0.18
Vig1			1.00	0.28 0.005	0.04 0.72	-0.32 0.02	0.20 0.04	0.02 0.86	-0.01 0.93
Vig2				1.00	0.46 <.0001	0.07 0.63	0.51 <.0001	0.41 <.0001	0.06 0.55
Mat					1.00	-0.09 0.54	-0.07 0.47	0.03 0.80	0.05 0.62
NTtl						1.00	0.085 0.56	0.12 0.40	-0.01 0.95
NO1							1.00	0.77 <.0001	0.09 0.39
NO2								1.00	0.24 0.02
NO3									1.00

Table 11. Correlation Matrix, Stockton Delta 2001, showing relationships among treatments and measured parameters, and respective statistical significance

	Trt	Yld	Vig1	Vig2	NTtl	NO1	NO2	NO3
Trt	1.00	0.23 0.04	0.18 0.44	0.36 0.12	0.08 0.75	0.50 0.001	0.56 0.0004	0.50 0.001
Yld		1.00	0.62 0.004	0.58 0.008	0.005 0.98	0.23 0.16	0.32 0.06	0.44 0.004
Vig1			1.00	0.62 0.004	-0.78 0.008	-0.21 0.38	0.25 0.28	0.21 0.38
Vig2				1.00	-0.57 0.08	0.16 0.50	0.60 0.005	0.44 0.05
NTtl					1.00	0.44 0.05	-0.08 0.75	-0.13 0.58
NO1						1.00	0.64 <.0001	0.48 0.002
NO2							1.00	0.72 <.0001
NO3								1.00

Table 12. Correlation Matrix, Four Locations, showing relationships among treatments and measured parameters, and respective statistical significance

	Trt	Yld	Vig1	Vig2	Mat	NTtl	NO1	NO2	NO3	NO4
Trt	1.00	0.39	0.49	0.62	-0.05	0.35	0.75	0.78	0.53	0.72
		<.0001	<.0001	<.0001	0.27	<.0001	<.0001	<.0001	<.0001	.0001
Yld		1.00	0.65	0.57	-0.03	0.09	0.43	0.22	0.34	0.21
			<.0001	<.0001	0.52	0.04	<.0001	<.0001	<.0001	0.0001
Vig1			1.00	0.66	-0.19	0.22	0.48	0.31	0.29	0.24
				<.0001	<.0001	0.0001	<.0001	<.0001	<.0001	<.0001
Vig2				1.00	-0.06	0.37	0.54	0.42	0.25	0.19
					0.21	<.0001	<.0001	<.0001	<.0001	0.01
Mat					1.00	-0.13	-0.06	0.08	0.02	0.05
						0.14	0.29	0.21	0.75	0.55
NTtl						1.00	0.25	0.23	0.08	0.34
							<.0001	0.0002	0.17	<.0001
NO1	1						1.00	0.80	0.53	0.79
								<.0001	<.0001	<.0001
NO2								1.00	0.51	0.80
									<.0001	<.0001
NO3									1.00	0.80
										<.0001
NO4										1.00
										<.0001

Table 13. Summary of Correlations between Yield and Petiole Nitrate Concentrations at Four Locations Throughout the Growing Season

Correlations Between Yield & Petiole NO_3 Levels				
	Sampling Time			
Location	**Pet1**	**Pet2**	**Pet3**	**Pet4**
Kern Co.	**0.50**	**0.35**	**0.32**	**0.15**
Stockton Delta	**---**	**0.23**	**0.32**	**0.44**
Davis	**0.50**	**0.40**	**0.39**	**0.30**
IREC	**---**	**0.52**	**0.43**	**0.13**

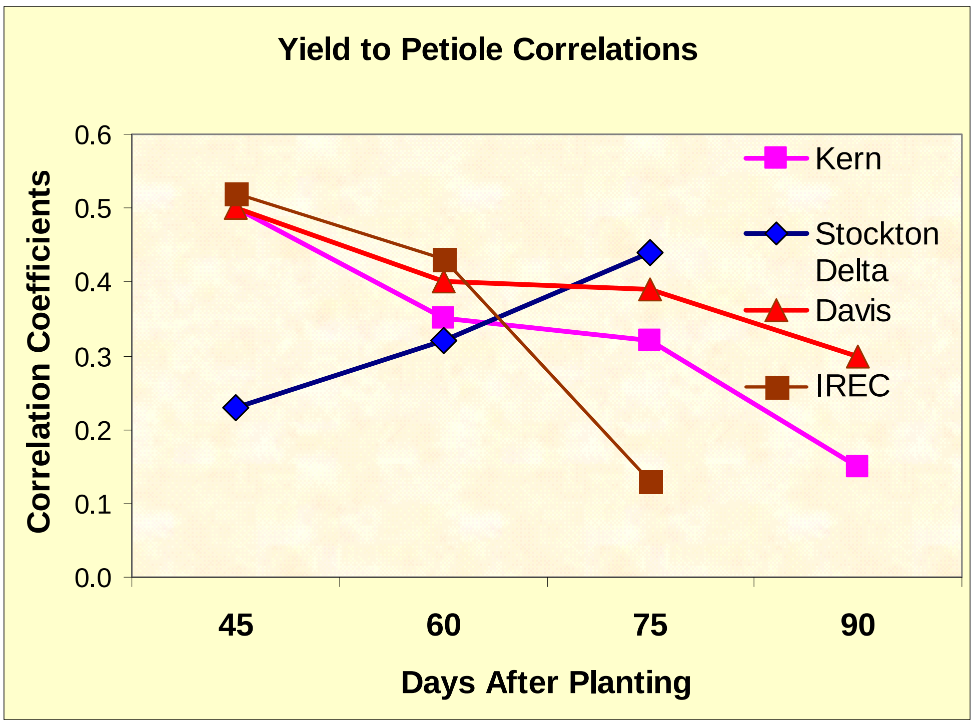

Figure 5a. Correlation between Yield and Petiole Nitrate throughout Season at Four Locations

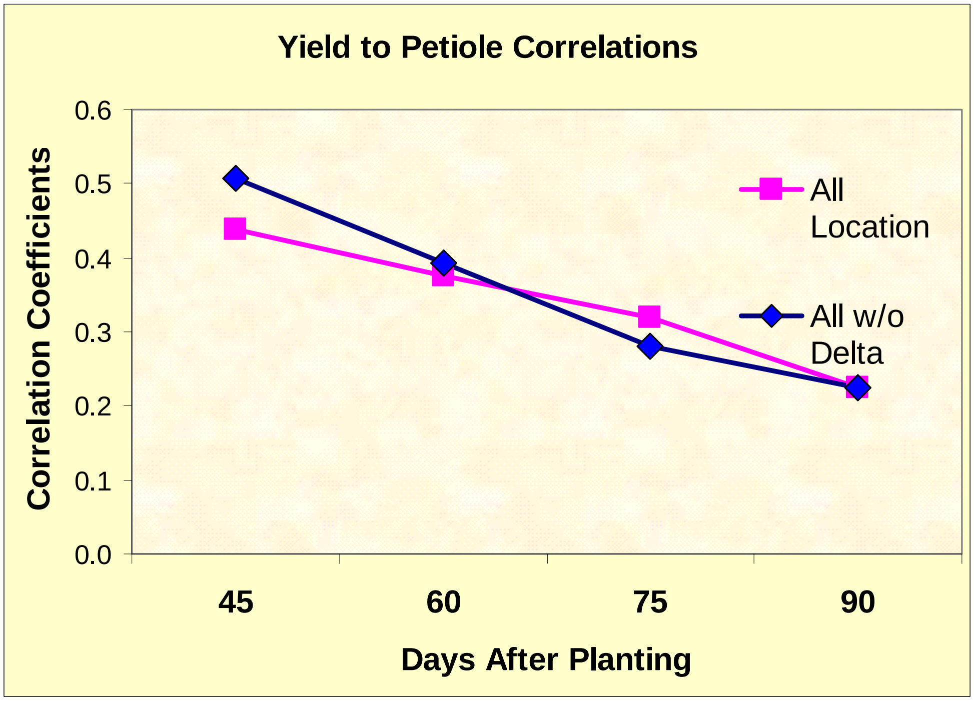

Figure 5b. Average Correlation between Yield and Petiole Nitrate throughout Season at Four Locations

Figure 6a illustrates the petiole nitrate concentrations at each of the four locations at the nitrogen fertilizer rate that produced the highest average yield of all varieties. At Davis and the Delta, this was the fourth rate, 225 lbs and 240 lbs/A, respectively. At Kern County and Tulelake, this was the fifth, or highest, rate, 320 and 400 lbs/A, respectively. The concentrations are shown over time from the earliest to latest sampling date for each respective location. This figure indicates that the optimum early season (approximately 60 days after planting) petiole nitrate concentration in Kern County is approximately 15,000 ppm. The similar value for Davis (approximately 55 DAP) is also 15,000 ppm. The corresponding values for Tulelake (approx. 65 DAP) and Delta (approx. 45 days) are 17,000 and 18,000 ppm. This figure clearly illustrates that the "critical level" of nitrate concentration for maximum yield decreases rapidly throughout the season. This rate of decrease was similar for all locations despite the large differences in yields at the respective locations. Figure 6b also illustrates the decreasing trends in each of the locations but at the average of all nitrogen fertilizer treatments. The usefulness of the figure is to again emphasize the similar slopes of the differing locations and the linear decrease in petiole nitrate concentration throughout the season.

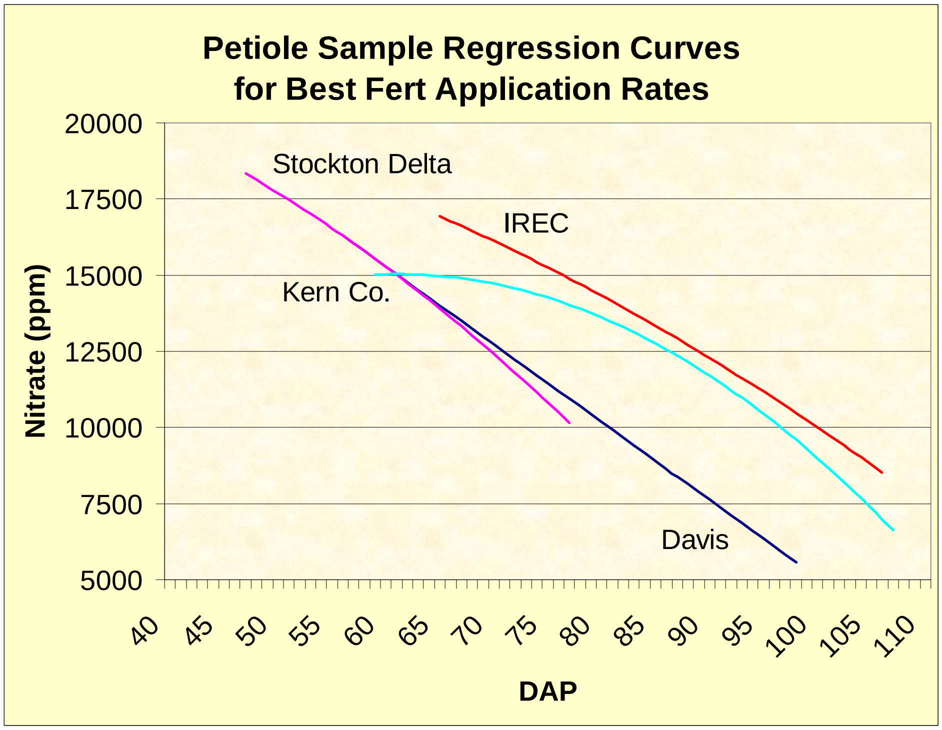

Figure 6a. Petiole Nitrate Concentrations over Time at Four Locations at the Nitrogen Fertilizer Rate that produced the highest yields, Average of all Varieties

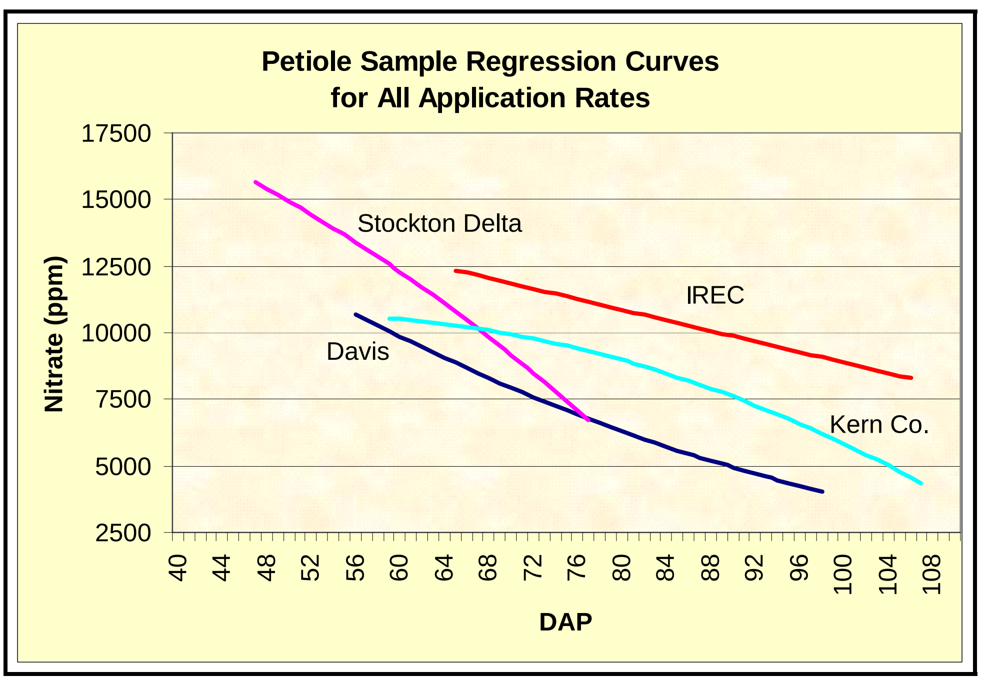

Figure 6b. Petiole Nitrate Concentrations over Time at Four Locations at the Average of the Respective Nitrogen Fertilizer Rates and Average of all Varieties

The individual location graphs, with corresponding quadratic equations, presented in Figures 7a – 7d, illustrate the relationship between petiole nitrate concentrations over time at only the nitrogen rates that produced the highest yields for Kern County 2001 (320 lbs/A), Davis 2000 (225 lbs/A), Tulelake 2000 (300 lbs/A) and Stockton Delta 2001 (240 lbs/A), respectively. Figure 7e illustrates the average of all four sites at the respective fertilizer rate with the highest yield (averaged over all varieties). The respective equations for Kern, Davis, Tulelake and the Delta are, in which "Y" is the petiole nitrate concentration observed at the maximum yield and "X" is the days after planting for sampling the petioles, as follows:

Kern County:	**$Y = 91 + 489X – 4X^2$**
Davis:	**$Y = 30{,}576 – 255X$**
Tulelake:	**$Y = 22{,}004 – 1.2X^2$**
Stockton Delta	**$Y = 23{,}195 – 2.2X^2$.**
Average All Locations:	**$Y = 26{,}759 – 186X$**

These equations can be used to calculate the optimum nitrate petiole nitrogen at any given days after planting at each of the respective locations. Thus, these data suggest that an average critical petiole nitrate concentration value for all varieties at all locations would be approximately 16,500 ppm at 55 DAP, 12,800 ppm at 75 DAP and 10,000 ppm at 90 DAP. The predicted critical values vary among locations. For example, the critical level at 55 DAP for Kern County, Davis, Tulelake and Delta, respectively, would be 14,900 ppm, 16,500 ppm,18,400 ppm, and 16,500 ppm.

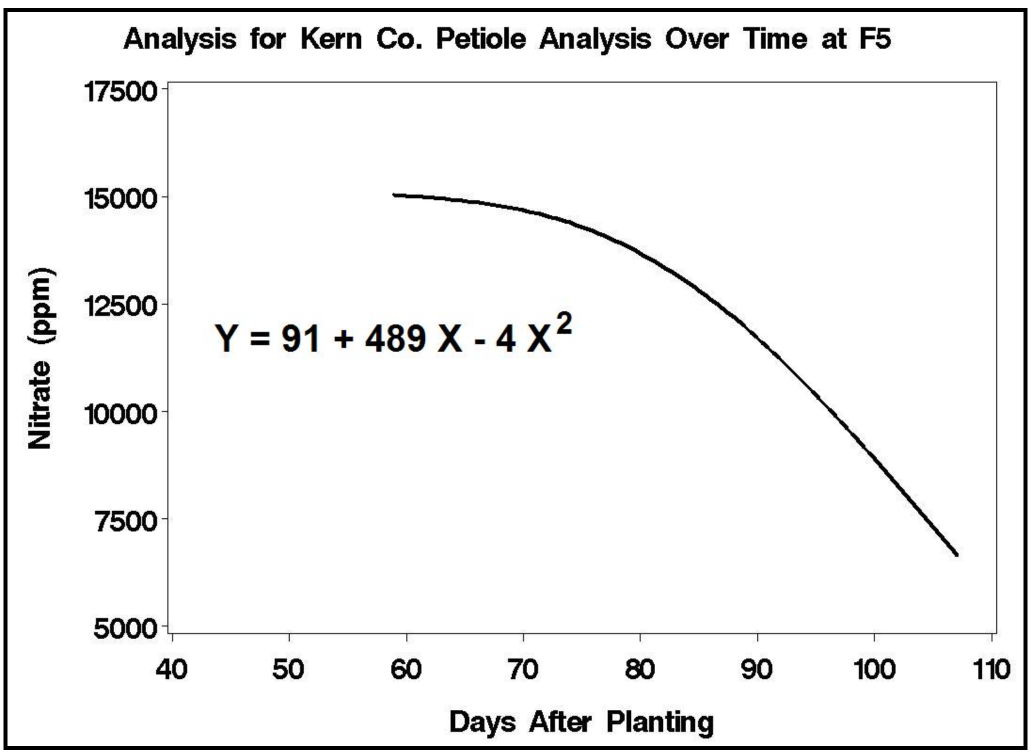

Figure 7a. Petiole Nitrate concentrations at Kern County 2001, averaged over all varieties, at petiole sampling dates from 59 to 107 days after planting.

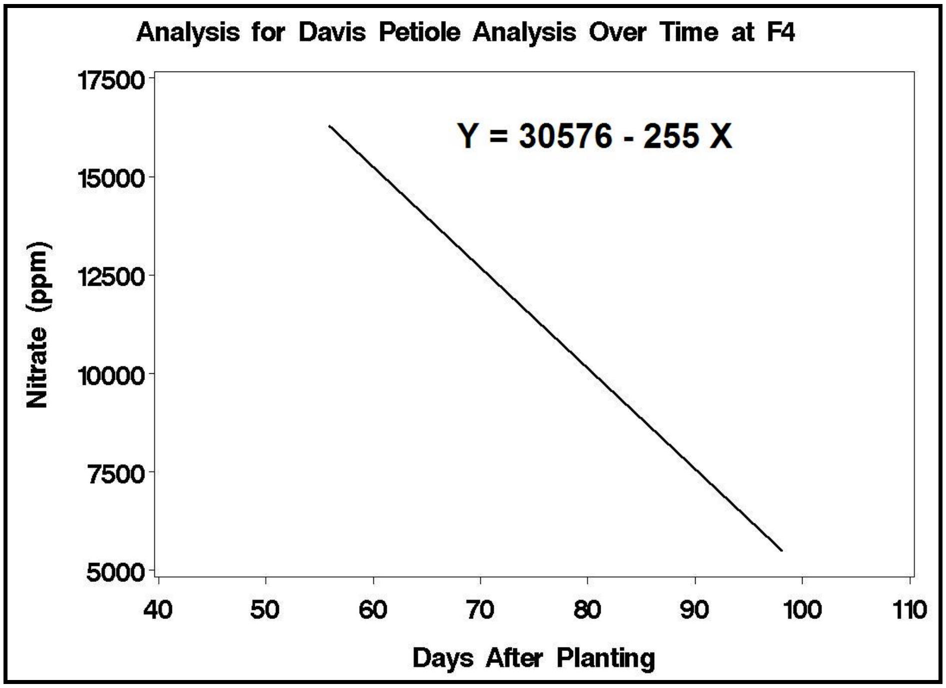

Figure 7b. Petiole Nitrate concentrations at Davis 2000, averaged over all varieties, at petiole sampling dates from 56 to 98 days after planting.

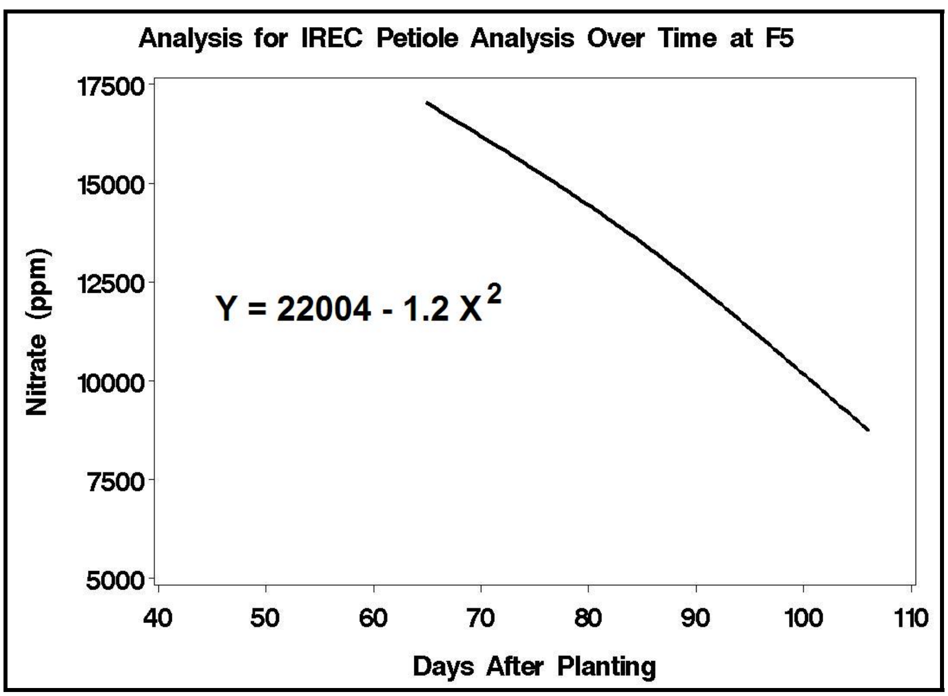

Figure 7c. Petiole Nitrate concentrations at Tulelake IREC 2000, averaged over all varieties, at petiole sampling dates from 65 to 106 days after planting.

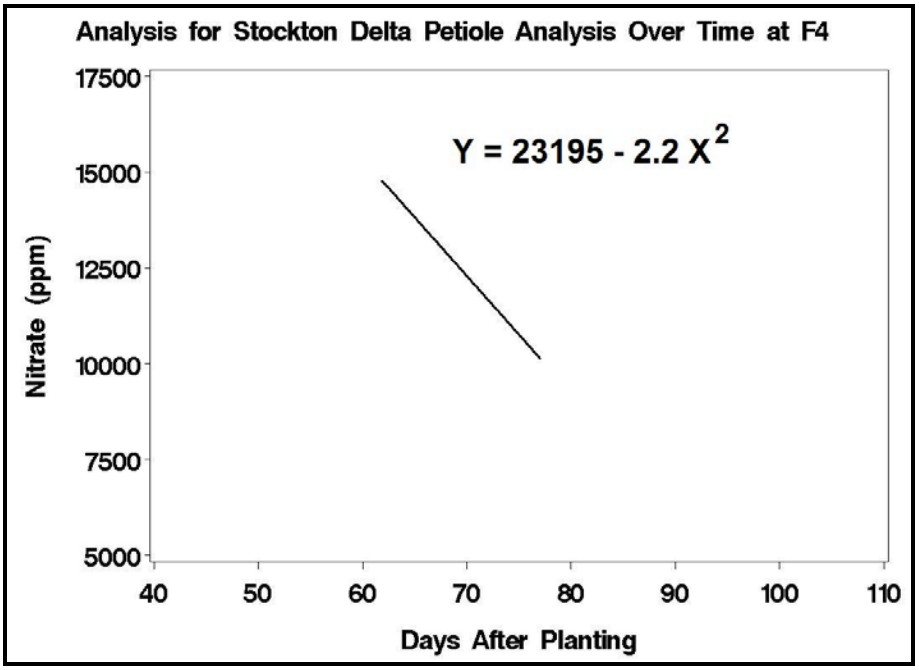

Figure 7d. Petiole Nitrate concentrations at Stockton Delta 2001, averaged over all varieties, at petiole sampling dates from 47 to 77 days after planting.

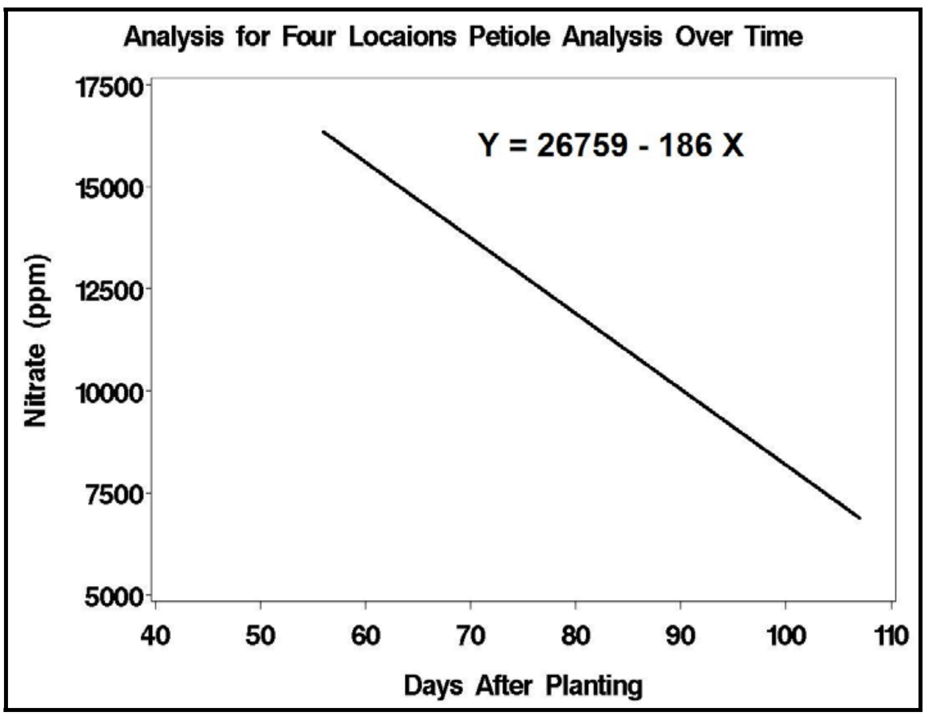

Figure 7e. Petiole Nitrate concentrations averaged over all four locations and all varieties, at petiole sampling dates from 47 to 106 days after planting.

All of these correlations / relationships are based on averages over all varieties and do not indicate any possible differences among the varieties. Thus, a series of figures are presented to illustrate the individual varieties and groups of varieties at the four locations.

Table 14 provides a summary of the petiole nitrate concentrations required for the highest measured yield at each of the locations for several varieties. Since one of the primary purposes of this study was to determine if Russet Norkotah and the strains of Russet Norkotah responded differently, that comparison is of interest. Although some differences occurred, it is apparent that the “critical nitrate levels” for Russet Norkotah and the strains are similar. Early season levels are approximately 17,000 to 20,000 ppm, mid-season levels are 12,000 to 17,000 ppm, and late season levels are 6,000 to 12,000 ppm. Similar values can be used for CalWhite and CalRed. Red LaSoda had highest yields at petiole nitrogen levels that are lower than the other varieties. “Critical levels” for Red LaSoda are estimated to be 15,000 to 17,000 ppm early season sampling, 12,000 to 15,000 ppm at mid-season, and 5,000 to 8,000 ppm at late season. While “critical levels” varied somewhat among locations, no consistent differences existed.

Table 15 lists the highest yield for several varieties at four locations, and the corresponding nitrogen fertilizer rate for each. These data suggest that the Russet Norkotah strains, while on the average higher yielding than Russet Norkotah, are equally responsive to nitrogen fertilizer. The highest yields of the strains resulted from nitrogen rates equal to, or higher than, Russet Norkotah. The strain CORN 3, however, does appear to achieve the same higher yields but with less fertilizer. On average of three locations, the corresponding highest yields for Russet Norkotah, average of three Russet Norkotah strains, and CORN 3 are 375, 430 and 425 cwt/A, respectively. The corresponding nitrogen fertilizer rates for these highest yields were 320, 335 and 270 lbs/A. CalRed had its highest yields at slightly lower nitrogen rates, and Cherry Red had its highest yields at significantly lower rates, than Russet Norkotah and its strains. CalWhite and Red LaSoda were similar to Russet Norkotah.

Table 14. Summary of Petiole Nitrate Concentrations for Maximum Yield for Several Varieties, Four Locations, and Five Sampling Dates

Petiole Nitrate Levels for Maximum Yield at each Sampling					
Variety /Location	Pet 1	Pet 2	Pet 3	Pet 4	Pet 5
Russet Norkotah					
Kern Co.	---	>22000	19000	13000	8200
Davis	---	17000	13000	>13200	6400
IREC	---	---	>17600	12000	---
Norkotah Strains					
Kern Co.	---	16700	14500	12000	10500
Davis	---	18000	17500	8300	6800
IREC	---	>16900	>19000	17000	---
CORN3					
Kern Co.	---	22400	20000	12500	11000
Davis	---	15500	12000	9600	5300
IREC	---	---	>17000	---	---
Cal White					
Stockton Delta	>20000	---	15500	10600	---
Davis	---	17000	11000	10800	7600
Red LaSoda					
Kern Co.	---	14500	14000	8100	3500
Davis	---	15200	12000	8100	6150
CalRed					
Kern Co.	---	15000	>19500	12500	>12800
Stockton Delta	---	---	---	12500	---
Davis	---	20000	15050	>13000	6500
IREC	---	---	>15900	>18750	---

Table 15. Summary of Fertilizer Rates and Corresponding Highest Yield for Several Varieties, and Four Locations

Fertilizer Rate and Yield at Maximum Yield for Each Variety at each Location					
Variety /Location	Kern	Davis	Tulelake	Delta	Average
Russet Norkotah					
Fertilizer Rate, lbs N/A	320	225	350		320
Yield, cwt/A	290	270	625		375
Norkotah Strains					
Fertilizer Rate	320	210	400		335
Yield	365	330	625		430
CORN3					
Fertilizer Rate					270
Yield					425
Cal White					
Fertilizer Rate	320	225		200	260
Yield	545	380		405	430
Red LaSoda					
Fertilizer Rate	320	200			260
Yield	575	385			450
CalRed					
Fertilizer Rate	300	275	400	240	250
Yield	220	245	520	280	325
Cherry Red					
Fertilizer Rate	240	190			200
Yield	350	330			345

Specific relationships between variety and nitrogen response, and between petiole nitrate concentration and nitrogen fertilizer rate.

Figures 8a – 8b illustrate the yield responses of the various varieties to nitrogen fertilizer rates at the different locations.

Figure 8a illustrates the yield responses to Russet Norkotah, TXNS112, TXNS223, CORN 3 and the average of the three strains, averaged over three locations – Kern County 2001, Davis 2000 and Tulelake 2000. These graphs and regression equations indicate 1) that the three strains are, in general, are higher yielding than the regular Russet Norkotah, 2) that the response to nitrogen fertilizer is generally the same for Russet Norkotah and the average of the three strains, but 3) CORN 3 was not as responsive at the highest rates of nitrogen. CORN 3 achieved its highest yield at a lower rate than the other strains or regular Russet Norkotah. All three strains had slightly higher yields at all rates of nitrogen, compared with Russet Norkotah.

Figure 8b illustrates the yield response of individual varieties – Russet Norkotah, the Russet Norkotah strains, CalRed, Cherry Red, Red LaSoda and CalWhite – to nitrogen fertilizer treatments. Comparisons of these response curves indicate that Cherry Red and Red LaSoda are the most responsive to low rates of nitrogen, with the highest yields resulting from medium to medium-high nitrogen rates. CalWhite was slightly less responsive to lower rates with highest yield at a slightly higher nitrogen rate. Russet Norkotah and the strains were less responsive at lower nitrogen rates but required higher rates to achieve the highest yields. CalRed was the least responsive to nitrogen, at all rates, with the highest yield resulting from medium-high nitrogen. The amount of yield increases from the lowest to the highest rates of nitrogen was only approximately 110 cwt/A for CalRed, approximately 170 cwt/A for Russet Norkotah, 180 cwt/A for average of Russet Norkotah strains, 215 for CalWhite, 220 cwt/A for Cherry Red, and 320 cwt/A for Red LaSoda.

Petiole concentrations at highest yield were compared at each location for each variety at the respective sampling dates. At Kern County 2001, the respective petiole concentrations at the earliest sampling date at which highest yields occurred for Russet Norkotah, CORN 3, all RN strains, CalWhite, CalRed, and Red LaSoda were 26,000 ppm, 23,600 ppm, 16,500 ppm, 11,500 ppm, 14,600 ppm and 14,500 ppm (Figure 9a). These comparisons indicated that Russet Norkotah and the Russet Norkotah strains have a significantly higher critical petiole nitrate level than the reds and whites.

At Davis 2000, sampling date 1, the respective petiole concentrations at which highest yields occurred for Russet Norkotah, CORN 3, all RN strains, CalWhite, CalRed and Red LaSoda were 17,500 ppm, 15,800 ppm, 18,750 ppm, 16,400 ppm, 19,900 ppm and 15,000 ppm. These comparisons are illustrated in Figure 9c.

At Tulelake 2000, all yields and petiole concentrations at the first sampling date were still increasing at the highest nitrogen rates (Figure 9e). Thus, no maximum petiole concentration at the highest yield was predicted by regression analyses. The only conclusions that can be made are that the earliest sampling date petiole nitrate concentrations were all greater than 17,000 ppm for the russet varieties and greater than 16,000 ppm for CalRed.

At the second sampling dates, the concentrations were lower. At Kern County 2001, the respective petiole concentrations at the earliest sampling date at which highest yields occurred for Russet Norkotah, CORN 3, all RN strains, CalWhite, CalRed, and Red LaSoda were 19,600 ppm, 20,500 ppm, 14,400 ppm, 11,500 ppm, 12,200 ppm, and 14,200 ppm (Figure 9b). These petiole concentrations strongly indicate that Russet Norkotah and its strains require continued high levels of nitrate in the plant for maximum yield and significantly higher concentrations than the other varieties.

At Davis 2000, sampling date 2, the respective petiole concentrations at which highest yields occurred for Russet Norkotah, CORN 3, all RN strains, CalWhite, CalRed and Red LaSoda were 12,800 ppm, 12,100 ppm, 13,600 ppm, 10,600 ppm, 14,600 ppm and 11,500 ppm (Figure 9d). These values also suggest that Russet Norkotah and its strains require higher nitrate concentrations in the petiole than other varieties. Also, as in Kern County, CalRed requires higher concentrations than Red LaSoda, Cherry Red or CalWhite.

As with the first sampling date at Tulelake, since maximum yields were not achieved at any of the fertilizer rates, most of the petiole levels at the second sampling date also did not reach maximum concentrations (Figure 9e). It appears, however, that Russet Norkotah and its strains require a continued high level of nitrate in the petioles, perhaps as high as in the first sampling date, to achieve maximum yield.

These graphs illustrate that one general equation for each location, relating yield to nitrogen fertilizer rate and yield to petiole nitrate concentration, is not adequate. For the most accurate relationships, each variety at each site must be considered. Relative relationships among varieties were consistent, but absolute relationships were not.

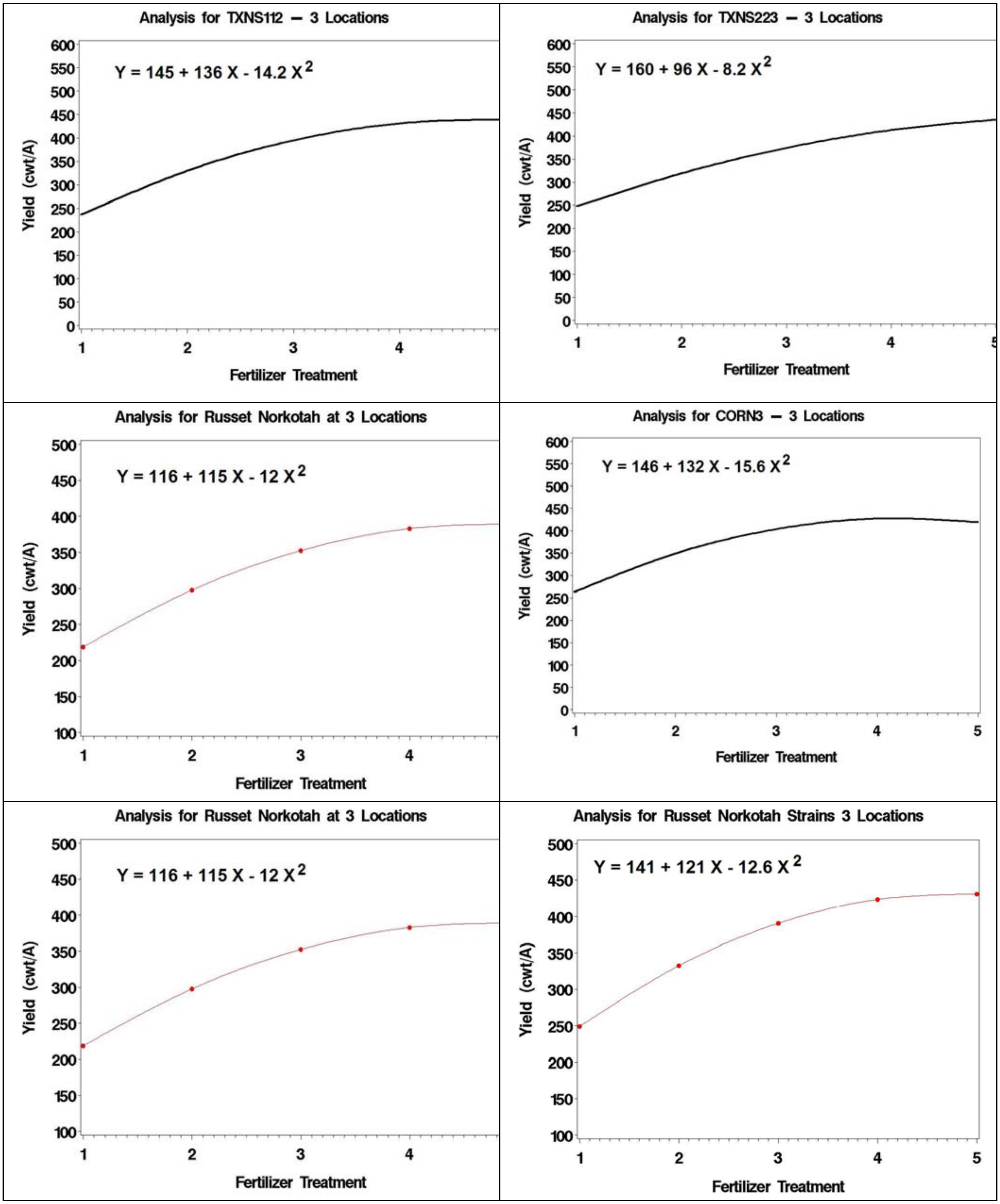

Figure 8a. Yield Response of Russet Norkotah and three Norkotah strains to nitrogen fertilizer treatments

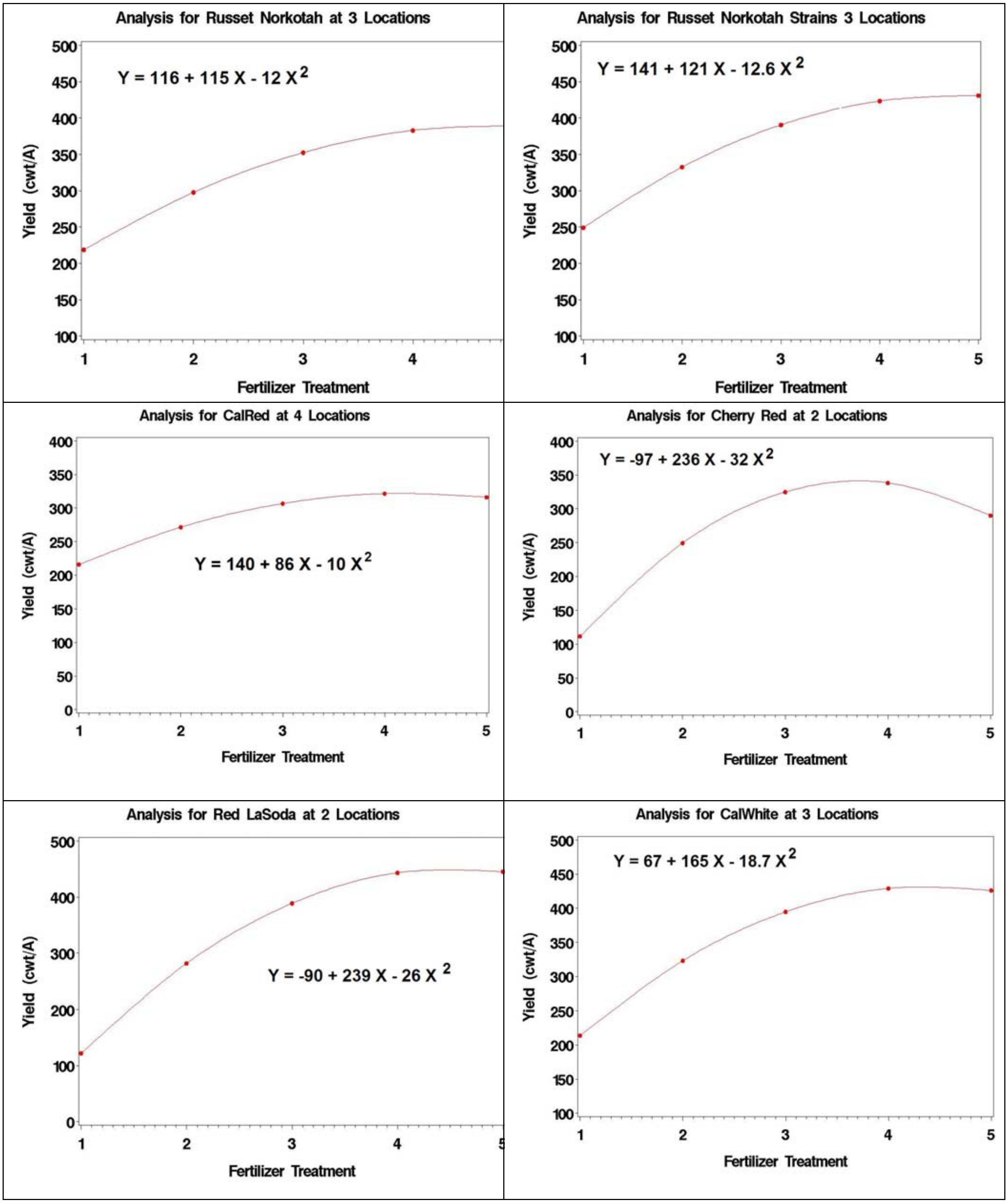

Figure 8b. Yield Response of Russet Norkotah, Russet Norkotah Strains, CalRed, Cherry Red, Red LaSoda and CalWhite to nitrogen fertilizer treatments

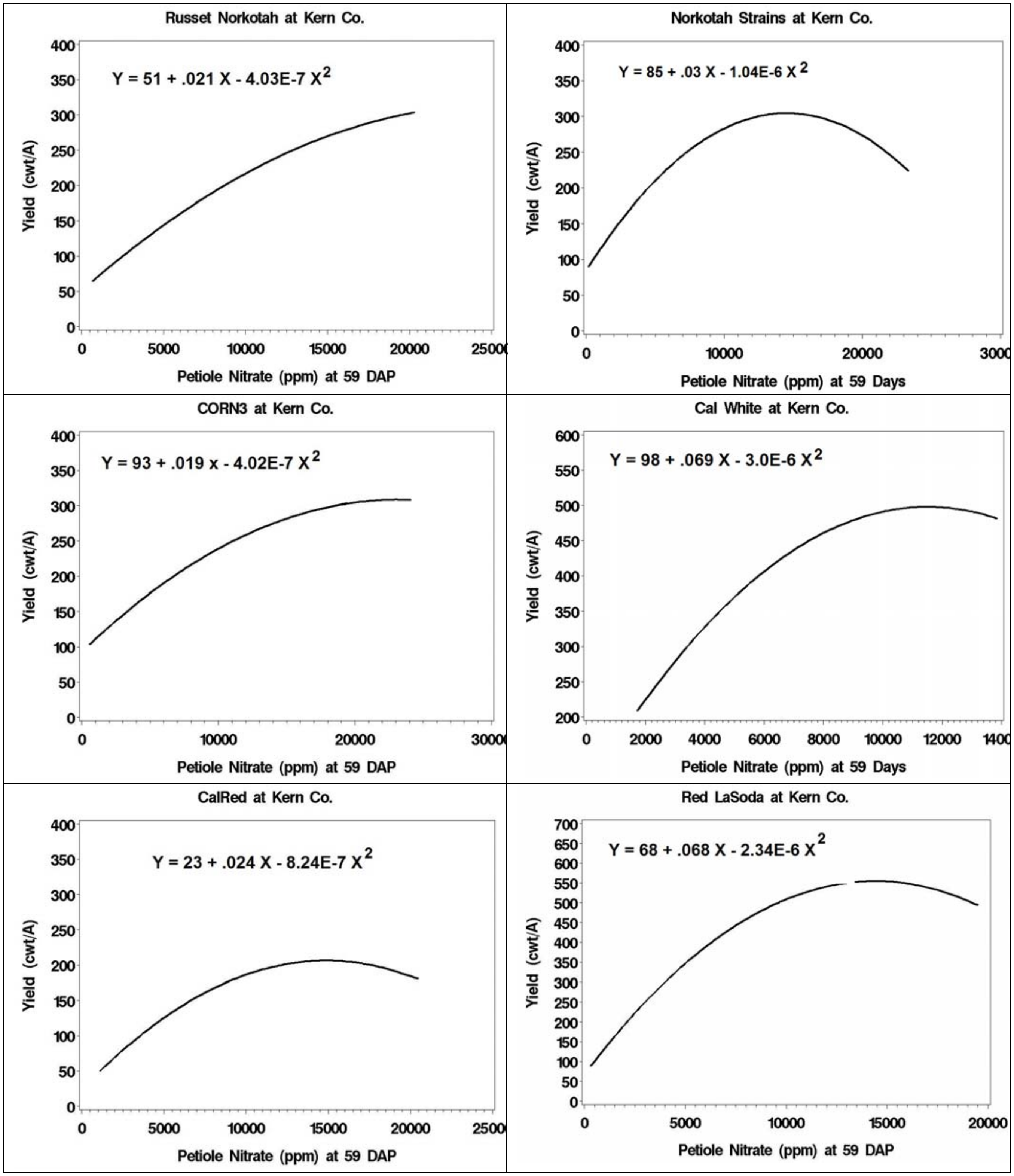

Figure 9a. Yield response in petiole nitrate concentration of individual varieties, Kern 2001, petiole sampling date 1 (59 DAP).

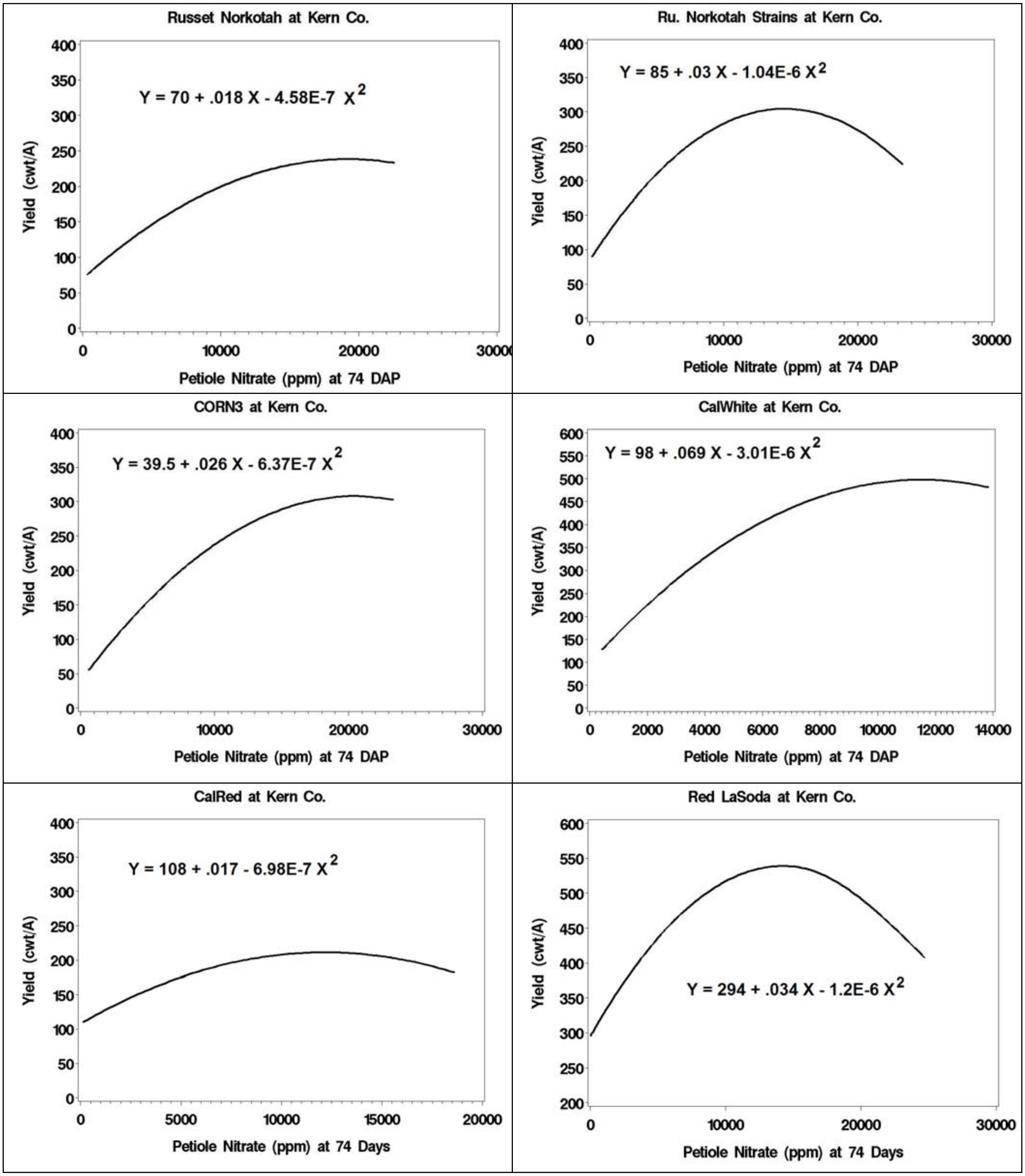

Figure 9b. Yield response in petiole nitrate concentration of individual varieties, Kern 2001, petiole sampling date 2 (74 DAP).

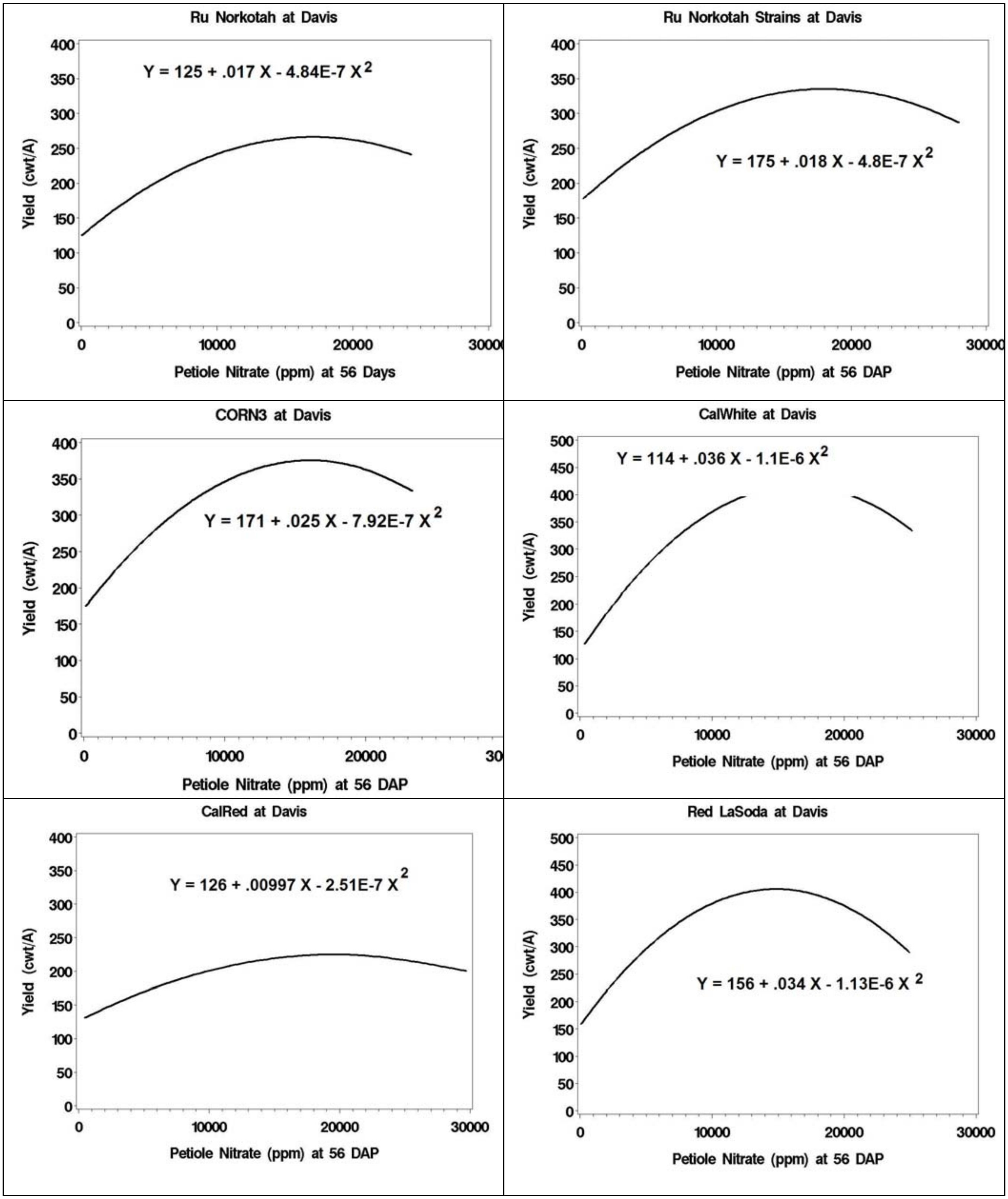

Figure 9c. Yield response in petiole nitrate concentration of individual varieties, Davis 2000, petiole sampling date 1 (56 DAP).

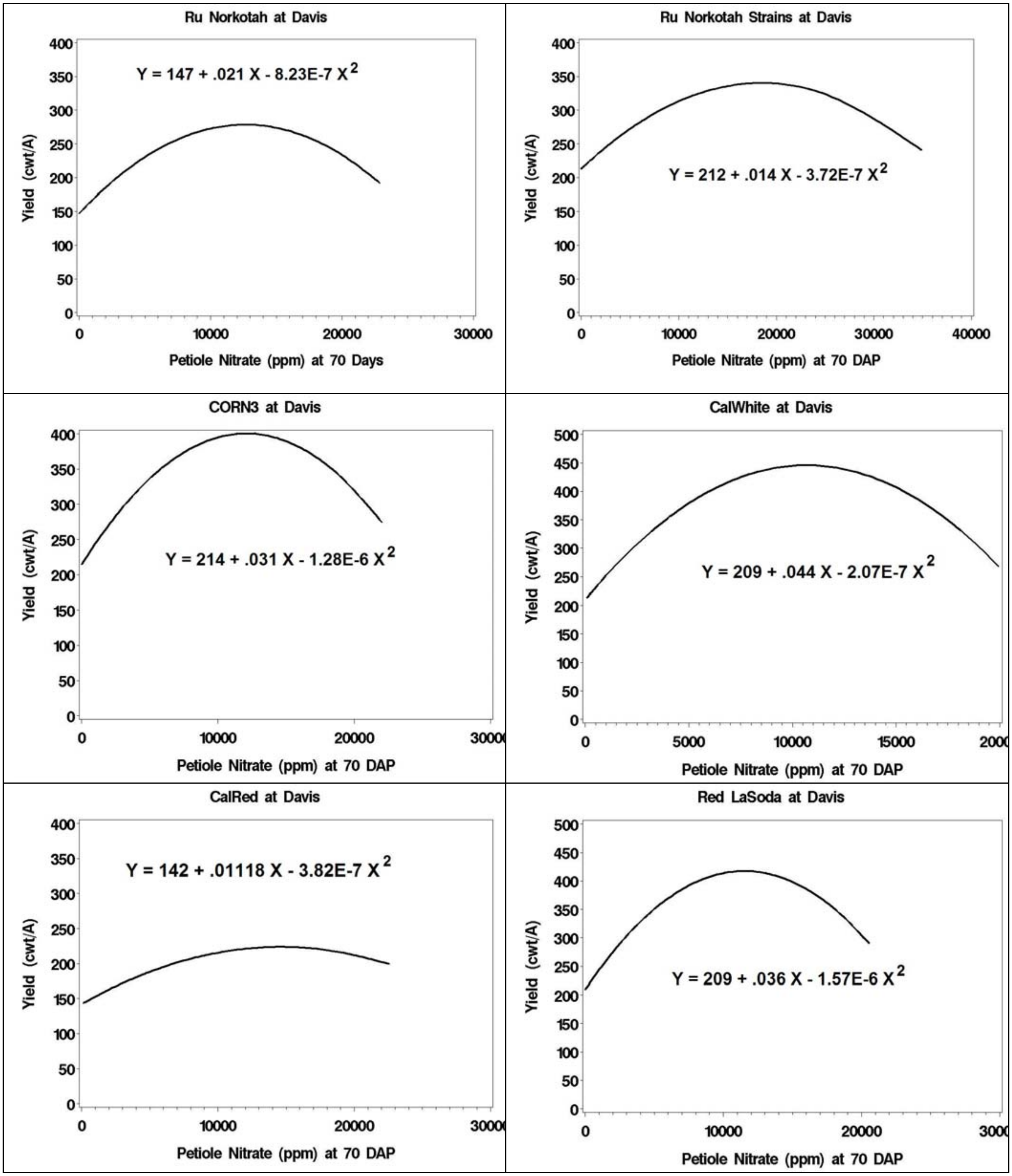

Figure 9d. Yield response in petiole nitrate concentration of individual varieties, Davis 2000, petiole sampling date 1 (70 DAP).

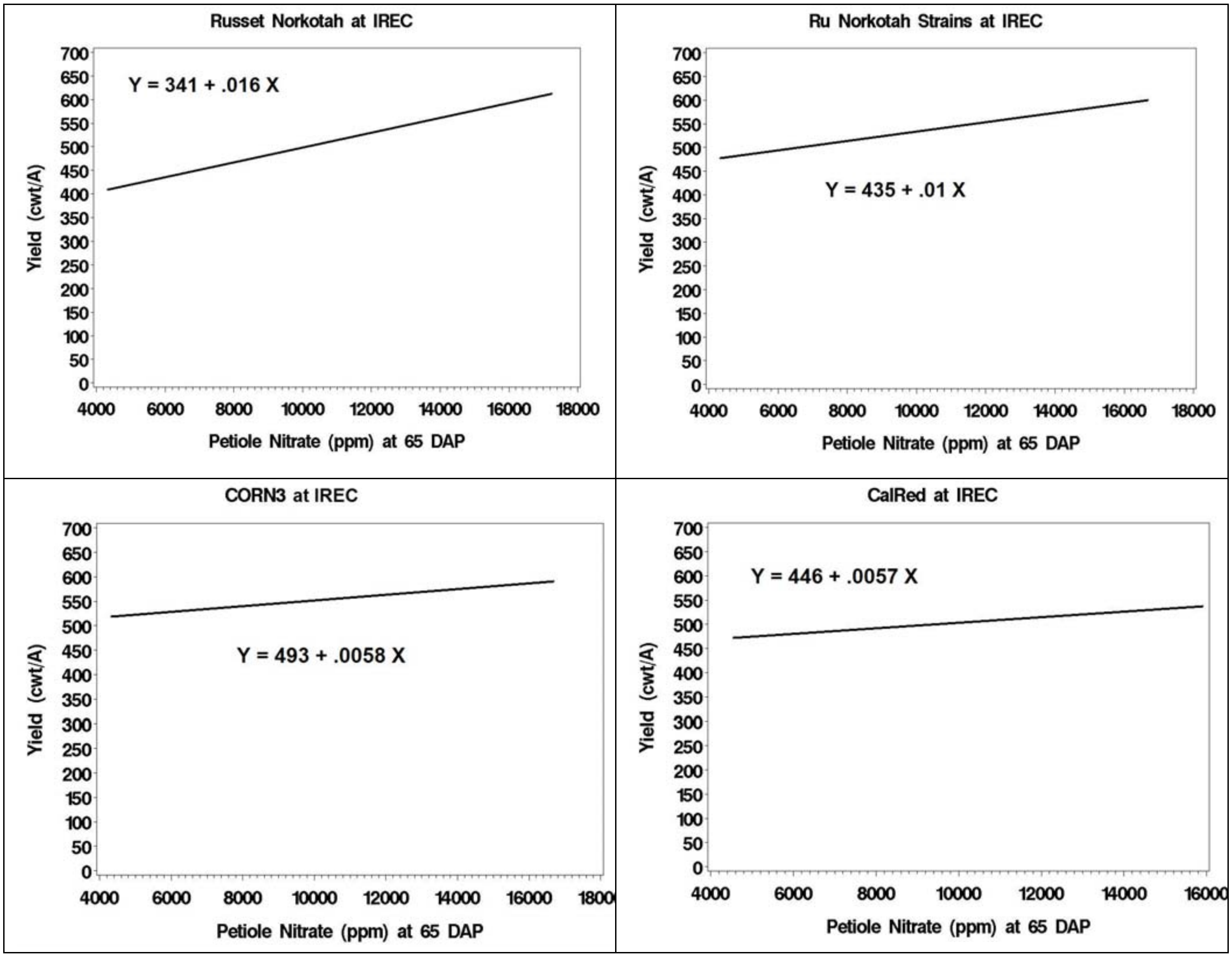

Figure 9e. Yield response in petiole nitrate concentration of individual varieties, IREC 2000, petiole sampling date 1 (65 DAP).

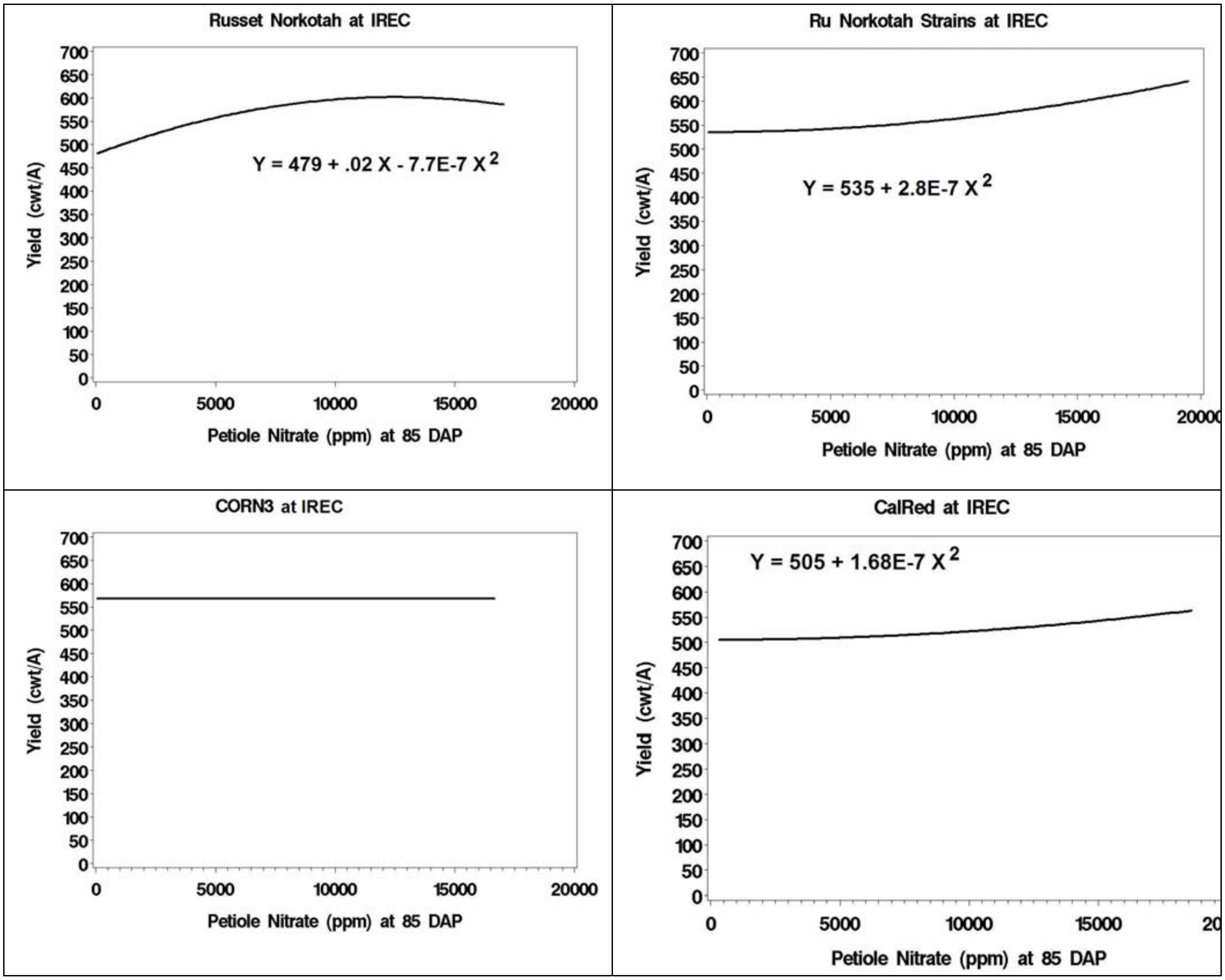

Figure 9f. Yield response in petiole nitrate concentration of individual varieties, IREC 2000, petiole sampling date 2 (85 DAP).

Summary and Conclusions

Potato is one of the important vegetable crops grown in California. Potato is also one of the heaviest fertilized crops in California. An average of approximately 300 lbs. of nitrogen fertilizer per acre is applied, with rates varying from 100 to over 400 lbs/Ac. The most widely grown variety (Russet Norkotah) has a weak vine and is susceptible to early dying diseases. To compensate for these variety deficiencies, growers have increased the amount and duration of nitrogen fertilization in an effort to keep the vines alive longer and healthier. Several new clonal selections of Russet Norkotah have stronger vines and later maturity. Preliminary indications are that nitrogen fertilizer needs are lower than the standard Russet Norkotah. New red, russet and white skinned varieties are also being developed and grown that may have lower nitrogen requirements than the previous or current standard varieties. New varieties are also being grown and/or recently released in the long white, round red, as well as russet market classes. These varieties (e.g. CalWhite, CalRed, Silverton Russet, and Klamath Russet) may also have lower nitrogen requirements. Numerous advanced selections and clones are evaluated annually. For economic and environmental reasons, these clones should be selected to produce well under conditions of relatively low input.

Nitrogen rate x variety experiments were conducted in three major production areas for three consecutive years each. Ten trials were conducted in the four years of the study. Trials were conducted in Kern County and in the Tulelake Basin 2000 - 2002. Trials were conducted in the Stockton Delta in 2001 - 2003, and one trial was conducted at UC Davis in 2000. The number of varieties in each trial has varied from six to fifteen entries. A total of 8 russets (four early maturing and four late maturing), 2 long whites, and 14 red varieties (nine named varieties and five numbered advanced selections) were studied. Thus, a total of 24 varieties were evaluated, some in only one location/experiment, others in as many as seven experiments at all four locations. Five nitrogen rates were utilized in each trial. An effort to have a zero (0) rate was made, but some trials were grown in grower's fields with unavoidable sprinkler applied and/or pre-plant applied nitrogen. The maximum rate varied based on the experience in the respective locations, from 300 to 400 pounds N per acre. Applications were split into two equal components at most locations, with half at planting and half as a side-dress 45-60 days after planting.

Soil samples were collected at the beginning and end of growing seasons. Petiole samples were accomplished at most locations at 15-day intervals. Numerous analyses were conducted on each sample, but petiole nitrate concentration was the parameter that was highly related to both fertilization rate and yield response.

Complete data collection, summarization and analyses were performed at all locations. With the numerous sites with experimental difficulties, only one year at each location was selected for complete interpretative analyses. Those four sites – 2000 Davis, 2000 Tulelake, 2001 Kern County and 2001 Stockton Delta – are the basis of most of this report, including the conclusions and recommendations.

To provide some consistency across locations and varieties, not all 24 varieties were selected for interpretative analyses. Those included were five russets – the late maturing Russet Burbank, early maturing Russet Norkotah, and three Russet Norkotah strains, CORN 3, TXNS 112 and TXNS 223; three reds – high vigor Red LaSoda, low vigor CalRed, and intermediate vigor Cherry Red; and high yielding, early maturing CalWhite. Russet Norkotah and its strains were included in three locations, CalRed was included in four locations, and the other entries were included in two locations.

Nitrogen fertilizer rate was highly correlated with yield, plant vigor, and petiole nitrate concentrations at all sampling dates. Nitrogen rate was not related to maturity, a parameter that is much more influenced by variety. The first petiole sampling date had the highest correlation with yield, and the correlation decreased with time. The nitrate petiole concentration at the first sampling is the best predictor of plant vigor as well as relative yield.

Russet Norkotah strains, while on the average higher yielding than Russet Norkotah, are equally responsive to nitrogen fertilizer. The highest yields of the strains resulted from nitrogen rates equal to, or higher than, Russet Norkotah. The strain CORN 3, however, does appear to achieve the same higher yields but with less fertilizer. On average of three locations, the corresponding highest yields for Russet Norkotah, average of three Russet Norkotah strains, and CORN 3 were 375, 430 and 425 cwt/A, respectively. The corresponding nitrogen fertilizer rates for these highest yields were 320, 335 and 270 lbs/A. CalRed had its highest yields at slightly lower nitrogen rates, and Cherry Red had its highest yields at significantly lower rates, than Russet Norkotah and its strains. CalWhite and Red LaSoda were similar to Russet Norkotah.

The three Russet Norkotah strains are, in general, higher yielding than the regular Russet Norkotah, they respond to nitrogen fertilizer generally the same as Russet Norkotah, but CORN 3 was not as responsive at the highest rates of nitrogen. CORN 3 achieved its highest yield at a lower rate than the other strains or regular Russet Norkotah. All three strains had slightly higher yields at all rates of nitrogen, compared with Russet Norkotah.

Cherry Red and Red LaSoda are the most responsive to low rates of nitrogen, with the highest yields resulting from medium to medium-high nitrogen rates. CalWhite was slightly less responsive to lower rates with highest yield at a slightly higher nitrogen rate. Russet Norkotah and the strains were less responsive at lower nitrogen rates but required higher rates to achieve the highest yields. CalRed was the least responsive to nitrogen, at all rates, with the highest yield resulting from medium-high nitrogen. The amount of yield increases from the lowest to the highest rates of nitrogen was only approximately 110 cwt/A for CalRed, approximately 170 cwt/A for Russet Norkotah, 180 cwt/A for average of Russet Norkotah strains, 215 for CalWhite, 220 cwt/A for Cherry Red, and 320 cwt/A for Red LaSoda.

Petiole nitrate concentrations at each of the four locations at the nitrogen fertilizer rate that produced the highest average yield of all varieties were used to predict optimum “average” nitrate levels. At Davis and the Delta, the yields were highest at the fourth nitrogen rate, 225 lbs and 240 lbs/A, respectively. At Kern County and Tulelake, this was the fifth, or highest, rate, 320 and 400 lbs/A, respectively. The “critical level” of nitrate concentration for maximum yield decreases rapidly throughout the season. This rate of decrease was similar for all locations despite the large differences in yields at the respective locations.

The respective predictive equations for Kern, Davis, Tulelake and the Delta were, in which "Y" is the petiole nitrate concentration observed at the maximum yield and "X" is the days after planting for sampling the petioles, as follows:

Kern County:	$Y = 91 + 489X - 4X^2$
Davis:	$Y = 30{,}576 - 255X$
Tulelake:	$Y = 22{,}004 - 1.2X^2$
Stockton Delta	$Y = 23{,}195 - 2.2X^2$.
Average All Locations:	$Y = 26{,}759 - 186X$

These equations can be used to calculate the optimum nitrate petiole nitrogen at any given days after planting at each of the respective locations. These data suggest that an average critical petiole nitrate concentration value for all varieties at all locations would be approximately 16,500 ppm at 55 DAP, 12,800 ppm at 75 DAP and 10,000 ppm at 90 DAP. The predicted critical values vary among locations. For example, the critical level at 55 DAP for Kern County, Davis, Tulelake and Delta, respectively, would be approximately 15,000 ppm, 16,500 ppm,18,500 ppm, and 16,500 ppm. These equations were based on the average of the varieties evaluated and not to a specific variety. Analyses of individual varieties at individual locations indicate that significantly higher levels are required at some sites for some varieties.

One of the primary purposes of this study was to determine if Russet Norkotah and the strains of Russet Norkotah responded differently. Although some differences occurred, the "critical nitrate levels" for Russet Norkotah and the strains, on average, are similar. Early season levels are approximately 17,000 to 20,000 ppm, mid-season levels are 12,000 to 17,000 ppm, and late season levels are 6,000 to 12,000 ppm. Similar values can be used for CalWhite and CalRed. Red LaSoda had highest yields at petiole nitrogen levels that are lower than the other varieties. "Critical levels" for Red LaSoda are estimated to be 15,000 to 17,000 ppm early season sampling, 12,000 to 15,000 ppm at mid-season, and 5,000 to 8,000 ppm at late season. While "critical levels" varied somewhat among locations, no consistent differences existed.

Russet Norkotah and the Russet Norkotah strains have a significantly higher critical petiole nitrate level than the reds and whites. At Kern County 2001, the respective petiole concentrations at the earliest sampling date at which highest yields occurred for Russet Norkotah, CORN 3, all RN strains, CalWhite, CalRed, and Red LaSoda were 26,000 ppm, 23,6000 ppm, 16,500 ppm, ???, 14,6000 and 14,500 ppm (Figure 9a). At Davis 2000, sampling date 1, the respective petiole concentrations at which highest yields occurred for Russet Norkotah, CORN 3, all RN strains, CalWhite, CalRed and Red LaSoda were 17,500 ppm, 15,800 ppm, 18,750 ppm, 16,400 ppm, 19,900 ppm and 15,000 ppm. At Tulelake 2000, all yields and petiole concentrations at the first sampling date were still increasing at the highest nitrogen rates (Figure 9e). Thus, no maximum petiole concentration at the highest yield was predicted by regression analyses. The only conclusions that can be made are that the earliest sampling date petiole nitrate concentrations were all greater than 17,000 ppm for the russet varieties and greater than 16,000 ppm for CalRed. One general equation for each location, relating yield to nitrogen fertilizer rate and yield to petiole nitrate concentration, is not adequate. For the most accurate relationships, each variety at each site must be considered. Relative relationships among varieties were consistent, but absolute relationships were not.

This study indicates that the new strains of Russet Norkotah are more efficient users of nitrogen, thus have the potential for being both more profitable for growers and contributing less to potential nitrate pollution as runoff or in ground water. All of the Russet Norkotah lines, however, are less efficient than the leading red and long white varieties being grown in California. Red LaSoda, a long time standard red skinned variety, appears to among the most efficient, and does not require as high of rates of nitrogen fertilizer for maximum yields as the other varieties. It will be important for breeding and selection programs in the future to select and evaluate new varieties under conditions of low to moderate rates of nitrogen to achieve the goals of improved grower profitability and reduced pollution potential.

Predicting optimum fertilizer rates requires consideration of the soil type and variety. A general, average formula cannot be used. It will achieve neither goal. The use of soil analyses and petiole analyses is useful in predicting optimum fertilizer rates, maximum yields, and most efficient fertilizer rates.