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An Investigation of Current Potato Nitrogen Fertility Programs' Contribution to Ground Water Contamination

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Abstract**—**Nitrogen fertility is an important component for optimum potato yield and quality. Best management practices are necessary in regards to N applications to achieve these goals without applying excess N with may contribute to ground water contamination. Eight potato fields in the Southern San Joaquin Valley were sampled for nitrogen inputs and uptake, tuber and vine dry matter and residual soil nitrate-N. The fields had substantial soil nitrate-N prior to the potato crop. Nitrogen fertilizer was applied prior to planting and in irrigation water as needed based on in-season petiole sampling in accordance with published recommendations. Average total nitrogen uptake was 237 kg ha^{-1} on 63.5 Mg ha^{-1} tuber yield and nitrogen use efficiency was very good at 81 percent. Sixty-nine percent of the plant nitrogen was removed in tubers. Soil nitrate-N increased 14 percent from pre-plant to post-harvest averaged across all fields and was generally situated in the upper soil profile. Irrigation timing and amount applied did not move water into the lower profile except for a single location where nitrate also moved into the lower soil profile. Pre-plant soil analysis is important information to be used. Rotation crops having deeper rooting growth would be able to utilize nitrogen that remained in the soil profile.

Keywords**—**Potato, nitrogen fertilization, leaching potential, irrigation management.

I. Introduction

NITROGEN fertilizer is the most used and can be the most mismanaged nutrient input. Recent reports blame agriculture for the high nitrate levels in the Tulare Lake Basin aquifer. This has prompted additional scrutiny on nitrogen fertility programs in numerous crops grown in the Southern San Joaquin Valley. Nitrogen management has tremendous implications on crop productivity, quality, and environmental stewardship. Sufficient nitrogen is needed to optimum yield and quality. Nitrates in the soil solution are highly mobile and can be moved beyond the root zone through excessive irrigation. Differences in soil type, potato variety, and potential yield are important considerations when making nitrogen fertilizer recommendations. Soil and in-season plant tissue testing for nitrogen status are a time consuming and expensive process. However, a nitrogen management plan that includes pre-plant and in-season testing along with optimum irrigation management can produce optimum tuber yield and quality and at the same time minimize the movement of nitrogen beyond the root zone and thus the potential for ground water contamination. The objectives of the study are to document if the current nitrogen fertility programs utilized in commercial fields contribute to nitrate leaching and calculate a nitrogen balance of N removal through harvest and N remaining in the soil for subsequent crops.

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II. Materials and Methods

Eight commercial potato fields throughout Kern County, California were monitored for nitrogen status. Fields were selected for different soil types. Soil texture ranged from sand to loam. Most fields were sandy loam soils. Soil samples to 180 cm deep in 30 cm increments were taken for nitrate status before planting and after harvest at four locations in each field. Farming operations used were typical for the area. Potato varieties were chipper and fresh market types. Fields were planted from January through March and harvested from May through July. All fields were sprinkler irrigated.

The 4th upper most leaves were sampled during bulking for N concentration. Four non-destructive instruments were used to assess plant nitrogen content. The Spectrum® FieldScout® CM 1000 NDVI meter uses ambient and reflected light in the 660 and 840 nm wavelengths to calculate a relative chlorophyll index. The Konica® Minolta® SPAD 502 Plus, and the Opti-Sciences® CCM-200 meters clamp on a leaf and utilize 650 and 940 nm wavelengths and 653 and 931 nm wavelengths, respectively, to determine a relative chlorophyll index. The Opti-Sciences® CCM-300 uses the ratio of fluorescence emission at 735 nm and 700 nm as there is a linear response to chlorophyll content in a range from 41 mg m^{-2} to 675 mg m^{-2}.

Vines and tubers were collected, oven-dried, weighed and analyzed for total N content. Tubers were hand harvested from three meters of row. As tubers were harvested, vines were separated from tubers and collected. This included leaves, above and below ground stems and some roots. Pre-plant and post-harvest soil samples along with plant and tuber samples were collected from the same area of each field using GPS coordinates. Nitrogen fertilizer application information and ambient irrigation water nitrate levels were supplied by the growers.

Growers used in-season petiole nitrate tests to adjust in-season nitrogen fertilizer applications to maintain petiole nitrate levels within established guidelines. N fertilizer was included in 10 to 14 irrigations during the season depending on the field. Nitrogen partitioning and removal from the field (tuber N concentration on fresh weight basis X yield) was calculated as part of the total N balance. Irrigation water volume was measured using rain gauges. The top of each rain gauge was set at 40 cm above the soil surface. WaterMark® soil moisture sensors were placed at 60 and 120 cm below the soil surface in each field. Soil moisture was measured each minute and hourly averages were recorded on WatchDog® data loggers. Soil, plant, and tuber samples were analyzed for N content at the UC Davis Analytical Lab.

Soil texture and soil moisture/sensor reading (kPa) relationship were determined in the lab. Soil texture by depth was determined using the industry standard methodology. Field capacity was determined in the lab in small containers with three replications. Soil moisture sensors were imbedded in approximately 400 grams of dry soil in a small cup. The bottom of each cup was perforated to allow excess water to drain. The soil was thoroughly wetted, 24 hours later it was thoroughly wetted a second time, then the sample was allowed to dry. The containers were weighed twice each day. Soil moisture sensor reading and water content by weight at 24 hours after the second thorough wetting was determined to be field capacity. A soil moisture/sensor reading regression line was calculated and used to determine 65% of field capacity.

III. Results and Discussion

Leaf nitrogen concentration at bulking ranged from 35 to 51 mg g^{-1} (Table I). This measurement was made late in the growing season and for most sites is within published guidelines [1]. Site #8 was above the sufficiency level. Chlorophyll meter readings were poorly correlated with leaf N as R^2 values ranged from 0.0014 to 0.14. Other researchers have found good correlations [2]-[4]. Leaf nitrogen was not compared to petiole nitrogen as sampling dates did not coincide.

TABLE I
Leaf Nitrogen at Bulking

Site #	N Content	Meter Reading			
		CM 1000	SPAD	CCM 200	CCM 300
	mg g^{-1}	meter reading			
1	36.4	0.683	50.8	35.3	434.7
2	34.8	0.815	39.1	17.9	411.2
3	38.6	0.890	43.0	22.6	332.8
4	40.0	0.858	45.8	28.3	449.8
5	36.2	0.875	50.7	37.5	395.5
6	43.1	0.908	48.7	36.4	423.2
7	38.1	0.888	46.5	27.8	475.7
8	51.4	0.868	42.9	26.6	440.9
Average	39.8	0.848	45.9	29.1	420.4
Standard Error	1.0	0.013	0.805	1.318	10.9

Vine nitrogen concentration at harvest ranged from a low of 18 to a high of 45 mg g^{-1} (Table II). Vine nitrogen content ranged from 30 kg N ha^{-1} at site # 2 to 180 kg N ha^{-1} at site #8. The varieties planted at sites #7 and #8 were used because they developed very large plants to protect tubers from excessive heat. Dry matter accumulation was one and one half to two times the average and these fields were managed for July harvest. Vines at sites #7 & #8 were not killed prior to harvest. Averaged across all fields, 31% of the total N was contained in the vines. This is consistent with data reported by [5] but higher than the 11 to 19% reported by [6] and [7].

TABLE II
Vine Nitrogen at Harvest

Site #	N Content	Dry Matter	Total Vine Nitrogen		
	mg g^{-1}	kg ha^{-1}	kg ha^{-1}	Standard Error	% of total
1	30.4	1777	54.0	3.98	29
2	17.7	1617	29.6	6.64	18
3	26.9	1792	47.5	3.89	21
4	29.6	1656	49.4	6.40	30
5	44.5	1294	61.4	20.91	26
6	30.0	2584	66.9	10.66	41
7	27.7	3842	106.4	6.44	39
8	31.6	5635	180.0	29.16	41
Avg.	29.8	2524	75.8	9.16	31

Tuber N concentration ranged from 8 to 17 mg g^{-1} and averaged 11 mg g^{-1} (Table III). Others have reported tuber N from 3 to 17.5 mg g^{-1} [8], [9]. Tuber N concentrations from this study are in line with those reported by others [10]-[12]. Total N removed from the field in tubers ranged from 110 to 260 kg ha^{-1}.

TABLE III
Tuber Nitrogen at Harvest

Site #	N Content	Dry Matter		Total Nitrogen	
	mg g^{-1}	mg g^{-1}	kg ha^{-1}	kg ha^{-1}	Standard Error
1	14.8	203	9158	135	8.6
2	11.0	164	9929	149	12.7
3	12.9	183	14027	180	6.9
4	9.1	213	12458	115	16.9
5	8.0	258	21588	173	5.4
6	7.8	264	14085	110	12.4
7	10.9	233	15221	166	12.2
8	17.0	220	15534	260	20.9
Avg.	11.4	217	14000	161	9.0

Total plant N uptake ranged from 164 to 440 kg N ha^{-1} and averaged 237 kg N ha^{-1} (Table IV). Tuber yield ranged from 45.3 Mg ha^{-1} to 70.9 Mg N ha^{-1}. Average tuber yield was 63.5 Mg N ha^{-1} with 237 kg N ha^{-1} total uptake. Multiple sources report N uptake for a 56 Mg ha^{-1} yield from 225 to 270 kg N ha^{-1} [5], [13]. Sixty-nine percent of the total N taken up by the plants was removed from the fields in the tubers. This is lower than the 81 to 89 percent previously reported [6], [7] but in line with others [5], [14] and within reported tuber N range of 48 to 89 percent.

Composted manure was added to some of the fields. Nitrogen availability in the first year from added compost was estimated to be 40 percent of the measured nitrogen. This is the high end of the reported availability range which averaged about 20 percent [14]-[21].

Average nitrogen use efficiency (NUE) was calculated to be 81 percent plus or minus 4 percent. Others reported NUE from three to 144 percent [22]-[26] with an average of 50 to 60 percent average. The lowest NUEs reported were in rain-fed areas and had very different values depending on rainfall from year to year.

TABLE IV
TOTAL PLANT NITROGEN AT HARVEST

Site #	Tuber Yield	Tuber N	Total N Uptake	N Applied	Nitrogen Use Efficiency	
	Mg ha^{-1}	% of total	kg ha^{-1}	kg ha^{-1}	%	Standard Error
1	45.3	71	188.9	202	93.7	4.1
2	54.4	82	183.0	274	66.7	2.9
3	76.4	79	227.7	276	82.7	3.4
4	58.5	70	164.3	298	55.1	4.0
5	83.6	74	234.3	304	77.2	7.9
6	53.6	59	188.4	314	60.1	6.4
7	65.6	61	272.0	329	82.6	3.0
8	70.9	59	440.1	347	126.8	10.2
Avg.	63.5	69	237.4	292	80.6	4.2

Field averages for pre-plant soil nitrate-N ranged from seven to 31 mg kg^{-1} in the surface 30 cm of soil (Fig. 1). Individual samples ranged from three to 41 mg kg^{-1}. Soil nitrate below 30 cm ranged between five and 15 mg kg^{-1} with the exception of site #6 which had higher levels in the lower profile.

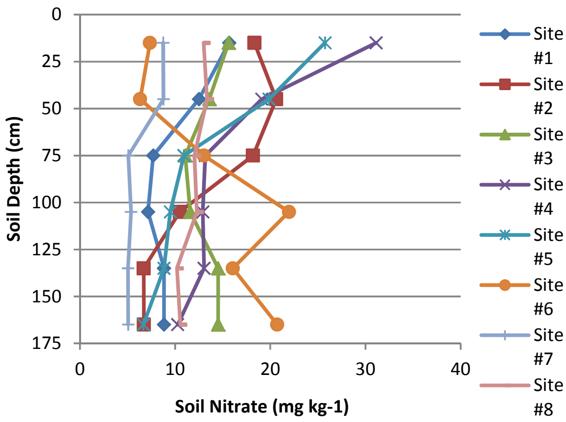

Fig. 1 Pre-plant soil nitrate-N by depth for each field

Field averages for post-harvest soil nitrate-N ranged from 10 to 38 mg kg^{-1} in the surface 30 cm of soil (Fig. 2). Individual samples ranged from 3 to 57 mg kg^{-1}. Soil nitrate-N below the 30 cm depth ranged between 3 and 24 mg kg^{-1}. A majority of the samples were between 10 and 15mg kg^{-1}.

Field averages for pre-plant to post-harvest change in soil nitrate-N ranged from -4 to 20 mg kg^{-1} in the surface 30 cm of soil (Fig. 3). Individual samples ranged from -12 to 47 mg kg^{-1}. The range of change of soil nitrate-N in the 30 to 60 cm depth was from -10 to 14 mg kg^{-1}. The range of change was equivalent in the upper two measured layers but the high and low were less. Below 60 cm soil depth the change in soil nitrate-N was between -5 and 8 mg kg^{-1}. The breadth of change was less in the 60 to 90 cm depth then remained equivalent for each subsequent depth.

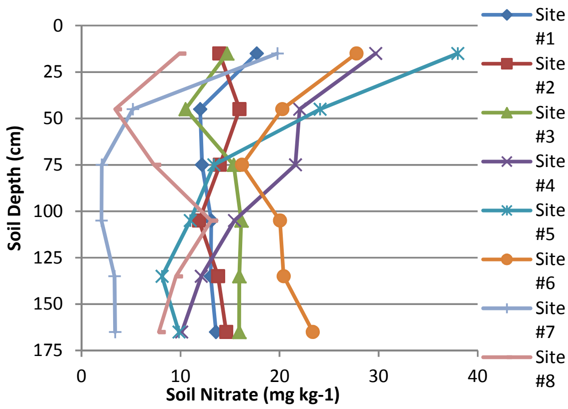

Fig. 2 Post-harvest soil nitrate-N by depth for each field

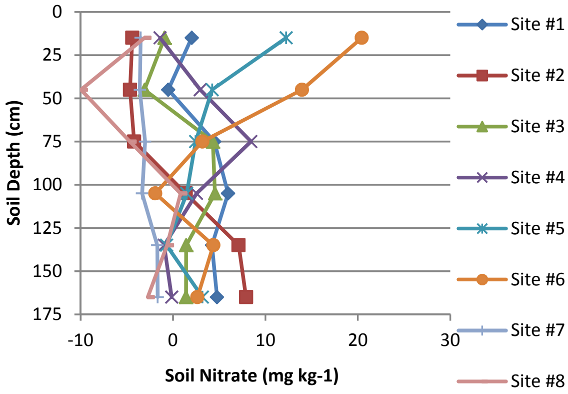

Fig. 3 Difference between pre-plant and post-harvest soil nitrate-N by depth for each field

Averaged across all fields pre-plant soil nitrate-N was 17 mg kg^{-1} in the surface 30 cm (Fig. 4). Pre-plant soil nitrate-N in the 30 to 60 cm depth averaged 14 mg kg^{-1} and in each 30 cm depth increment from 60 to 180 cm nitrate-N levels were between 10 and 11 mg kg^{-1}. Averaged across all fields post-harvest soil nitrate-N was 21 mg kg^{-1} in the surface 30 cm. Post-harvest soil nitrate-N in the 30 to 60 cm depth averaged 14 mg kg^{-1} and in each depth increment from the 90 to180 cm soil nitrate-N was 12 to 13 mg kg^{-1}. Averaged across all fields the change soil nitrate-N in the surface 30 cm was 5 mg kg^{-1}. There was no change in the 30 to 60 cm depth. The change in soil nitrate-N in each depth from 60 to 180 cm was between one and two mg kg^{-1}.

A substantial amount of nitrogen was in the soil profile prior to planting. Soil nitrate nitrogen in the surface 60 cm ranged from 61 kg ha^{-1} at site #6 to 225 kg ha^{-1} at site #4. Averaged across all fields, the highest amount (140 kg ha^{-1}) was in the 0 to 60 cm depth then decreased in the 60 to120 cm depth (102 kg ha^{-1}) and continued to decline to 93 kg ha^{-1} in the 120 to 180 cm depth (Table V). A different situation existed at site # 6 where nitrogen increased with depth. Potato roots can grow to a depth of 90 cm [27]-[29] but are generally concentrated within the upper 30 to 45cm. Rooting depth for various other crops used in these potato rotations include carrots with a rooting depth of 90 to 120 cm and wheat or corn with a rooting depth of 120 to180 cm [29], [30].

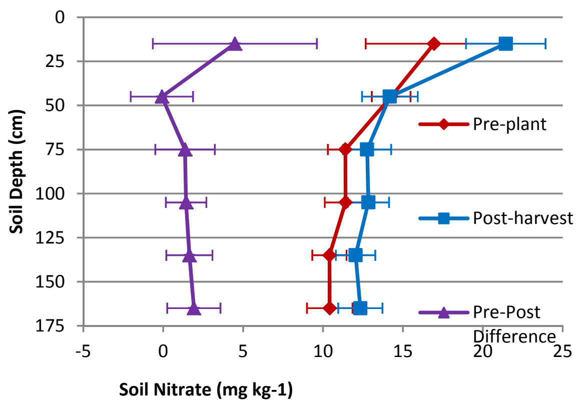

Fig. 4 Pre-plant, post-harvest and change in soil nitrate-N averaged across all fields

Substantial nitrate-N remained in the soil following harvest. There was 160 kg ha^{-1} in the surface 60 cm averaged across all fields. The amount varied greatly between fields ranging from 59 to 278 kg ha^{-1}. Equivalent amounts, about 110 kg ha^{-1} were measured in the 60 to 120 cm and the 120 to 180 cm depths.

TABLE V
SURFACE SOIL PROFILE NITRATE-N STATUS

	0-60cm Depth			60-120 cm Depth		
Site #	Pre-plant	Post-harvest	Diff.	Pre-plant	Post-harvest	Diff.
			kg ha^{-1}			
1	126	133	7	66	113	47
2	174	134	-40	128	116	-12
3	131	113	-18	102	141	39
4	225	232	7	116	165	49
5	204	278	74	91	109	18
6	61	216	155	157	163	6
7	78	112	34	47	19	-28
8	117	59	-58	109	92	-17
Avg.	140	160	20	102	114	12
	120-180cm Depth			0-180 cm Depth		
Site #	Pre-plant	Post-harvest	Diff.	Pre-plant	Post-harvest	Diff.
			kg ha^{-1}			
1	80	120	40	272	366	94
2	61	128	67	363	378	15
3	130	142	12	362	396	34
4	104	100	-4	445	497	52
5	69	81	12	365	468	103
6	165	196	31	381	573	192
7	46	30	-16	170	160	-10
8	92	77	-15	319	228	-91
Avg.	93	109	16	335	383	48

The change in pre-plant to post-harvest soil nitrate-N ranged from -91 to 192 kg ha^{-1} throughout the 180 cm profile. The initial low soil nitrate-N (62 kg ha^{-1}) in the surface 60 cm at site #6 had one of the highest levels (215 kg ha^{-1}) following harvest. This field had the highest increase in soil nitrate-N. In contrast, a decrease in nitrate-N was observed at each depth at site #8. The change in soil nitrate-N in the 60 to 120 and 120 to 180 cm depths did not show as large a range of change as observed in the surface 60 cm. The change in soil nitrate-N averaged across all fields was 48 kg ha^{-1} for the 180 cm soil profile with 42% of the change within the surface 60 cm. The change in soil nitrate-N was essentially zero at sites #2 and #7. Site #8 had a substantial decrease in soil nitrate-N. Two sites had a moderate increase (< 50 kg ha^{-1}) and three sites had a substantial increase (> 90 kg ha^{-1}).

A mass balance of nitrogen was calculated for each field. Total N available was the sum of pre-plant soil nitrate-N and added fertilizer (Table VI). Total N uptake and residual was the sum of N in vines, tubers, and post-harvest soil nitrate-N. Averaged across all fields the total available and total uptake and residual were equivalent. There were differences for individual fields as unaccounted for N ranged from -15% to +16% of the total uptake. There was only 7 kg ha^{-1} nitrogen unaccounted for when averaged across all fields. There are some assumptions and omissions made in the calculation. Only nitrate-N was measured in the soil. It is assumed that soil NH_4^+ was minimal. The assumed N availability from added compost was discussed previously and all available N from compost was included in the N applied total. Compost was applied prior to pre-plant soil sampling. Some mineralized N from compost would have also been measured as part of the pre-plant soil sample. Care was taken to collect all tubers and plant material during the hand harvest. Small tubers that would not have been collected with a mechanical harvester were included in the tuber yield. Roots and small stems that separated from the main vine were also not collected. No measurements of organic N, immobilization, or volatilization were made. Nitrate-N in irrigation water was assumed to be at the same concentration all season.

TABLE VI
NITROGEN BALANCE

Site #	Total N Available	Total N Uptake & Residual	Gain or Loss of Nitrate-N		
		kg ha^{-1}		Standard Error	%
1	474	555	81	35	15
2	637	560	-77	125	-14
3	638	625	-13	130	-2
4	744	662	-83	56	-12
5	669	702	33	84	5
6	696	762	66	62	9
7	500	432	-68	84	-16
8	667	669	2	93	0
Avg.	628	621	-7	30	-1

Soil moisture and irrigation amounts are shown for each site in Figs. 6-13. Optimum soil moisture for potato growth and quality is between field capacity and 65% of field capacity [31]. Soil moisture sensors were place to monitor water status below the effective rooting zone. Field soil moisture at the 120 cm depth was generally below field capacity. The exceptions are site #2 for most of the growing season and site #5 late in the growing season. Field soil moisture at the 60 cm depth also was generally below field capacity except for sites #2, #3and #5. At site #3 several irrigations pushed water below 60 cm in the soil profile (Fig. 8). There was a decrease in soil nitrate-N in the surface 60 cm, a moderate increase in the 60 to 120 cm soil depth and a small increase in the 120 to 180 cm depth. The higher than field capacity soil moisture measurements at site #5 late in the season appears to have moved a small amount of nitrate-N into the lower soil profile, however, most of the increased soil nitrate-N remained in the surface 60 cm of the soil profile. Site #6 had the greatest increase in soil nitrate-N. Eighty percent of the increased nitrate-N was in the surface 60 cm of the soil profile.

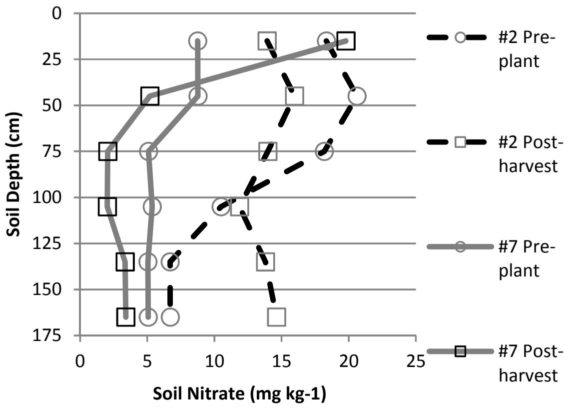

Fig. 5 Sites #2 & #7 pre-plant and post-harvest soil nitrate-N

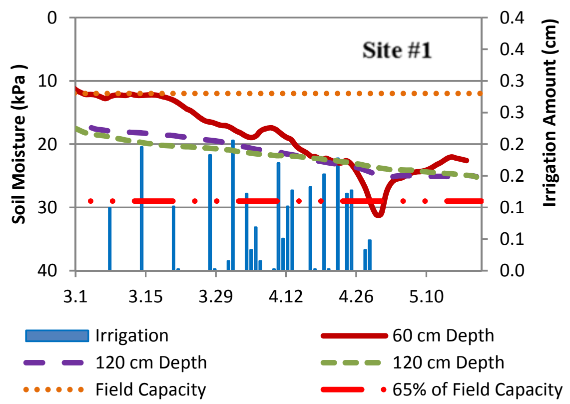

Fig. 6 Site #1 soil moisture and irrigation

Sites #2 and #7 had almost no change in soil nitrate-N from pre-plant to post-harvest measured over the entire soil profile, yet there was significant differences when evaluated at each depth. Site #2 had more nitrate move deeper into the soil profile from pre-plant to post-harvest (Fig. 5). Soil moisture data from that site indicated that the soil exceeded field capacity for about 2 months then remained about field capacity for the remainder of the growing season (Fig. 7). Soil moisture at the 120 cm depth initially was lower than field capacity but soon after rose to field capacity and remained at that level throughout the growing season. It did at times exceeded field capacity. The change in soil nitrate throughout the soil profile was only 15 kg of nitrogen ha^{-1}. In the upper 120 cm of the profile there was a reduction of 52 kg ha^{-1} of nitrate-N, however, there was an increase of 67 kg ha^{-1} of nitrate-N in the 120 to180 cm depth. The change in soil nitrate status deep in the soil profile was a result of the excess water application.

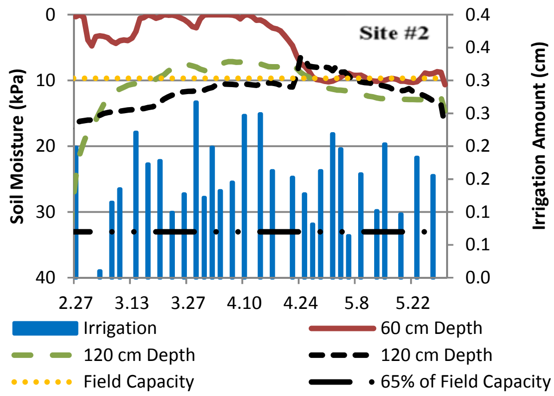

Fig. 7 Site #2 soil moisture and irrigation

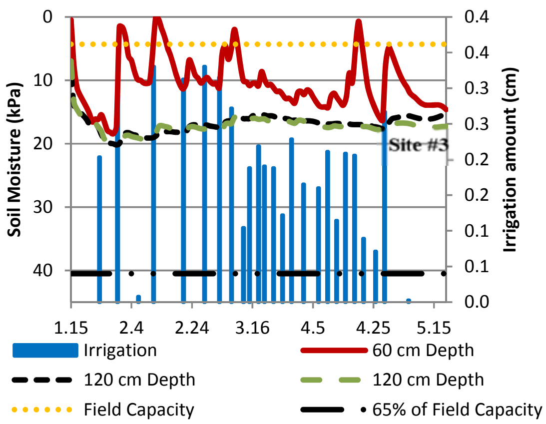

Fig. 8 Site #3 soil moisture and irrigation

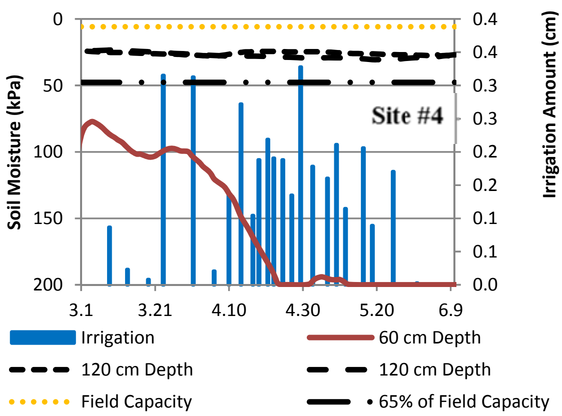

Fig. 9 Site #4 soil moisture and irrigation

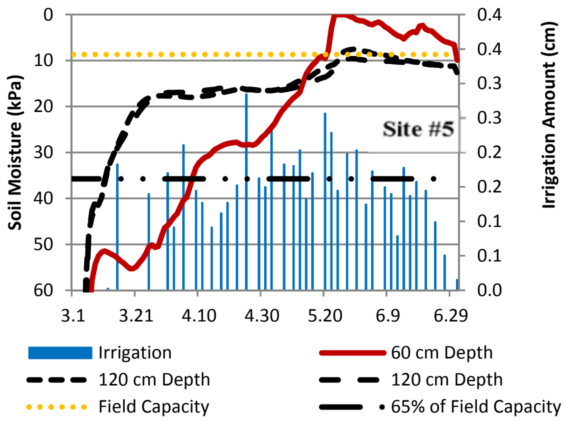

Fig. 10 Site #5 soil moisture and irrigation

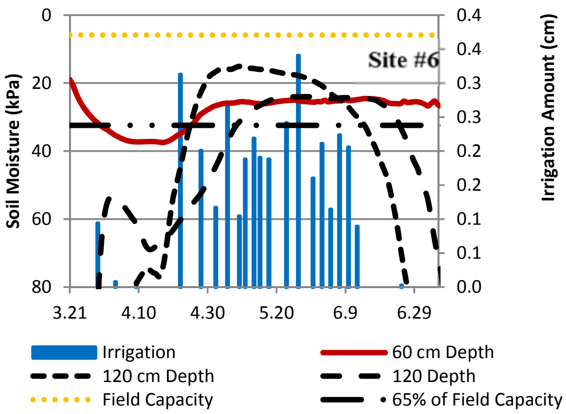

Fig. 11 Site #6 soil moisture and irrigation

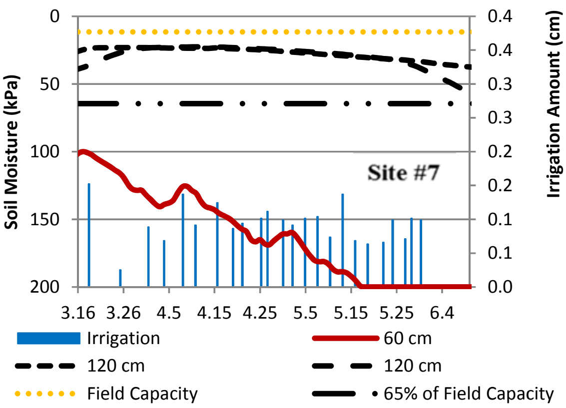

Fig 12 Site #7 soil moisture and irrigation

Site #7 had lower nitrate concentrations at post-harvest than pre-plant at all depths below the surface 30 cm (Fig. 5). An increase of 34 kg ha^{-1} nitrate-N in the surface 30 cm was offset by a decrease of 44 kg ha^{-1} in the 30 to180 cm depth. Soil moisture at the 60 cm depth decreased throughout the growing season (Fig. 12). Soil moisture at the 120 cm depth remained constant. The sandy loam soil texture at this site had more moisture holding capacity than the loamy sand soil at site #2.

At no time during the growing season did water move below the 60 cm depth.

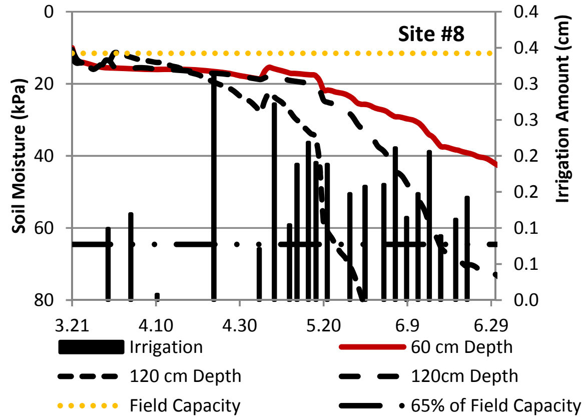

Fig. 13 Site #8 soil moisture and irrigation

IV. Conclusions

The fields that were sampled had substantial soil nitrate-N prior to the potato crop. It is imperative that pre-plant soil nitrogen be measured and that information be incorporated in nitrogen fertility recommendations. In-season petiole sampling for nitrogen level helped in scheduling in-season nitrogen fertilizer applications. Total nitrogen required for the yields obtained in the Southern San Joaquin Valley were consistent with previously published data and nitrogen use efficiency was a very good 81%. Averaged across all fields there was a 14% increase in soil nitrate from pre-plant to post-harvest. Generally the nitrate was located in the soil profile where typical rotation crops with deeper rooting growth would be able to take up the nitrogen. Irrigation scheduling is most critical to control movement of nitrate deeper into the soil profile. Where irrigation water did not move into the lower profile, soil nitrate remained in place.

Acknowledgment

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References

[1] Crozier, C., N. Creamer, M. Cubeta. 2004. Soil fertility management for Irish potato production in Eastern North Carolina. NC State Univ. Coop. Ext. AGW-439-49

[2] Cohen, Y., Y. Zusman, V. Alchanatis, Z. Bar, D. Bonfil, A. Karnieli, A Zilberman, A. Moulin, V. Ostrovsky, A. Levi, R. Brikman, and M. Shenker. 2008. Nitrogen evaluation in potato plants based on spectral data and on simulated bands of the VENμS satellite. Downloaded on 15 Dec. 2015 from http://www.agri.gov.il/download/files/Part%201-%20Single%20leaves%20Venus_1.pdf.

[3] Vos. J. and M. Bom. 1993. Hand-held chlorophyll meter: a promising tool to assess the nitrogen status of potato foliage. Potato Research 26:301-308.

[4] Young, M., D. Mackerron and H. Davies. 1997. Calibration of near infrared reflectance spectroscopy to estimate nitrogen concentration in potato tissues. Potato Research 40:215-220.

[5] Hopkins, B., J. Stark, D. Westermann and J. Ellsworth. Nutrient Management: Potato. Downloaded on 15 Dec. 2015 from http://ucanr.org/sites/nm/files/76642.pdf
[6] Alva, A., T. Hodges, R. Boydston and H. Collins. 2002. Dry matter accumulations and partitioning in two potato cultivars. Journal of Plant Nutrition 25:1621-1630.
[7] Biemond, H. and J. Vos. 1992. Effects of nitrogen on the development and growth of the potato plant. 2. The partitioning of dry matter, nitrogen and nitrate. Annals of Botany 70:37-45.
[8] Waddell, J., S. Gupta, J. Moncrief, C. Rosen and D. Steele. 1999. Irrigation and nitrogen management effects on potato yield, tuber quality, and nitrogen uptake. Agronomy Journal 91:991-997.
[9] Kavvadias, V., C. Paschalidis, G. Akrivos and D. Petropoulos. 2012. Nitrogen and potassium fertilization responses of potato (*Solanum tuberosum*) cs. Spunta. Communications In Soil Science and Plant Analysis 43:176-189.
[10] Saffigna, P., D. Keeney and C. Tanner. 1977. Nitrogen, chloride, and water balance with irrigated Russet Burbank potatoes in a sandy soil. Agronomy J. 69:251-257.
[11] Fontes, P., H. Braun, C. Busato and P. Cecon. 2010. Economic optimum nitrogen fertilization rates and nitrogen fertilization rate effects on tuber characteristics of potato cultivars. Potato Research 53:167-179.
[12] Arshadi, J. and M. Asgharipour. 2011. Effect of nitrogen top-dress management using chlorophyll meter on yield, quality and correlation between some agronomic traits in potato. Advances in Environmental Biology. 5:711-718.
[13] Westerman, D. 2005. Nutritional requirements of potato. American Journal of Potato Research 82:301-307.
[14] Eghball, B. 2000. Nitrogen mineralization from field-applied beef cattle feedlot manure or compost. Soil Sci. Soc. of Amer. J. 64:2024-2030.
[15] Wen, G., T. Bates and R. Voroney. 1995. Evaluation of nitrogen availability in irradiated sewage sludge, sludge compost and manure compost. J. Environ. Qual. 24:527-534.
[16] Munoz, G., K. Kelling, K. Rylant and J. Zhu. 2008. Field evaluation of nitrogen availability from fresh and composted manure. J. Environ. Qual. 37:944-955.
[17] Eghball, B. and J. Power. 1999. Composted and noncomposted manure application to conventional and no-tillage systems: Corn yield and nitrogen uptake. Agron. J. 91:819-825.
[18] Gale, E., D. Sullivan, C. Cogger, A. Bary, D. Hemphill and E. Myhre. 2006. Estimating plant-available nitrogen release from manures, composts and specialty products. J. Environ. Qual. 35:2321-2332.
[19] Rosen, C. and P. Beirman. 2005. Using manure and compost as nutrient sources for vegetable crops. U. Minn. Ext. Service. pp. 1-12.
[20] Gil, M., M. Carballo and L. Calvo. 2011. Modelling N mineralization from bovine manure and sewage sludge composts. Bioresource Technology 102:863-871.
[21] Pettygrove, G. A. Heinrich and D. Crohn. 2009. Manure nitrogen mineralization. UC Manure Technical Bulletin Series. pp 1-5.
[22] Zebarth, B., G. Tai, R. Tarn, H. deJong and P. Milburn. 2004. Nitrogen use efficiency characteristics of commercial potato cultivars. Can. J. Plant Sci. 84:589-598.
[23] Cambouris, A., B. Zebarth, M. Nolin and M. Lverdiere. 2008. Apparent fertilizer nitrogen recovery and residual soil nitrate under continuous potato cropping: Effect of N fertilization rate and timing. Can. J. Plant Sci. 88:813-825.
[24] Joern, B. and M. Vitosh. 1995. Influence of applied nitrogen on potato. Part II: Recovery and partitioning of applied nitrogen. American Potato Journal 82: 73-84.
[25] Saffigna, P., D. Keeney and C. Tanner. 1977. Nitrogen, chloride, and water balance with irrigated Russet Burbank potatoes in a sandy soil. Agron. J. 69:251-257.
[26] Hong, L., L. Parent, A. Karam and C. Tremblay. 2003. Efficiency of soil and fertilizer nitrogen of a sod-potato system in the humid, acid and cool environment. Plant and Soil 251:23-36.
[27] Iwama, K. 2008. Physiology of the potato: New insights into root system and repercussions for crop management. Potato Research 51:333-353.
[28] Ahmadi, S., P. Finn, M. Andersen, A. Sepaskhah and C. Jensen. 2011. Effects of irrigation strategies and soil on field grown potatoes: Root distribution. Agricultural Water Management. 98:1280-1290.
[29] Anon. 1983. Sprinkle Irrigation. Section 15, Natural Resources Conservation Service National Engineering Handbook. Chapter 11 pp 17.
[30] Thorup-Kirstensen, K., M. Cortasa and R. Loges. 2009. Winter wheat roots grow twice as deep as spring wheat roots, is this important for N uptake and N leaching losses? Plant and Soil 322:101-104.
[31] King, B. and J. Stark. 1997. Potato Irrigation. University of Idaho Cooperative Extension Bulletin 789. pp 1-15.