CALIFORNIA LETTUCE RESEARCH BOARD
April 1, 2012 – March 31, 2013

Title: Project title: Evaluation of best management irrigation and nutrient management practices (BMP) and treatment of nitrate in tile and surface water to safeguard water quality

Project Investigators: Richard Smith, and Mike Cahn, UCCE, Monterey County
Tim Hartz, University of California, Davis

SUMMARY

Water quality regulations proposed by the Central Coast Regional Water Quality Control Board (CCRWQCB) will likely require agriculture to reduce discharges of nitrate-nitrogen (NO_3-N) to surface and ground water. Monitoring carried out by the Cooperative Monitoring Program (CMP) of surface waters throughout the coastal lettuce production region have indicated that nutrient loads are commonly out of the acceptable range. To comply with proposed water quality regulations, growers on the Central Coast are in need of assistance in implementing practices that reduce losses of nitrate-N from vegetable fields.

The research reported here was comprised of four components: 1) evaluation of techniques to remove nitrate from tile and surface water runoff; 2) development of a nitrogen credit for crop residues of spinach, lettuce and cole crops; and 3) survey of drip tape uniformity and its impact on water and fertilizer application uniformity; and 4) spinach nitrogen nutrition evaluations: **1)** Nitrate was removed from tile and surface water runoff by use of bioreactors which are plastic-lined pits filled with wood chips through which tile drain effluent or surface runoff is channeled. The anaerobic conditions in these bioreactors allow the growth of bacteria that convert NO_3-N to atmospheric N_2. Denitrification rates observed to date suggest that between approximately 5-12 PPM NO_3-N can be removed from agricultural wastewater per day of residence time in a bioreactor, depending on water temperature. Lower initial NO_3-N concentration of surface runoff compared to tile drain effluent makes denitrification bioreactors more feasible for the treatment of surface runoff, provided that efficient sediment removal can be achieved. **2)** Spinach, lettuce and cauliflower residues at harvest contained 6.5, 3.5 and 3.1% N, respectively. Spinach mineralized 26-32 lbs N/A, lettuce 35 lbs N/A and cauliflower 80-180 lbs N/A over an 8-week incubation. These values give an estimate of the amount of nitrate and ammonium released from the residue of these crops that can be utilized by subsequent vegetable crops. **3)** Surveys of commercial lettuce fields suggested that N fertilizer applied by fertigation is often not distributed to fields uniformly due to poorly operated or maintained drip systems. The highest distribution of fertilizer measured was 82%, but the average distribution of fertilizer was less than 70% for the 11 fields evaluated. Operation procedures observed at these sites would suggest that irrigators may need training to better understand the principles of fertigation so that they can achieve the potentially highest distribution of fertilizer, and to prevent losses of nitrate forms of fertilizer below the rooting depth of the crop. **4)** Trials were conducted evaluating fertilizer technology to increase the N use efficiency of spinach. The controlled release fertilizer D45 and a nitrification inhibitor DMPP were evaluated. D45 was capable of releasing N quick enough to supply spinach which allowed the use of lower rates of N to achieve the same yield as the grower standard. The nitrification inhibitor DMPP slowed the mineralization of ammonium to nitrate for 18 days after application. Both of these fertilizer technologies show promise in improving nitrogen use efficiency in a fast growing, high density crops such as spinach.

CALIFORNIA LETTUCE RESEARCH BOARD
April 1, 2012 – March 31, 2013

Title: Evaluation and demonstration of best management irrigation and nutrient management practices (BMP) to safeguard water quality

Project Investigators: Richard Smith, and Mike Cahn, UCCE, Monterey County
Tim Hartz, University of California, Davis

Objectives: To fine tune nitrogen and irrigation management in commercial lettuce and spinach production:

1. Treatment of tile drain and surface water to remove nitrate with denitrification bed reactor
2. Development of a nitrogen credit from prior crop
3. Survey of drip tape uniformity and impact on water and fertilizer distribution
4. Spinach nitrogen nutrition evaluations

Procedures

1. Treatment of tile drain and surface water to remove nitrate with denitrification bed reactor

Two pilot-scale bioreactors were constructed in spring, 2011 on tile-drained commercial vegetable farms in the Salinas Valley. Pits of approximately 930 ft^3 (site 1) and 450 ft^3 (site 2) were dug, lined with polyethylene sheeting, and filled with chipped wood waste obtained from the Monterey Regional Waste Management District. This material was made by grinding untreated scrap construction wood. Pumps were installed in the collection sumps of the farms' tile drain systems. Tile drain water is continuously pumped into the bioreactors at a rate to provide an average of approximately 2 days of residence time before the water was released into the surface ditches draining the farm.

In May, 2012, a pilot-scale bioreactor was constructed on a commercial farm in the Salinas Valley (site 3) to evaluate the remediation of surface runoff from vegetable fields. This reactor is approximately 430 ft^3 in volume, and contains the same chipped wood waste used in the 2011 bioreactors, although of a finer grind (most chips < 1", whereas the 2011 bioreactors were filled with 1-2" chips). Water is continuously pumped into the bioreactor from a surface runoff collection pond. Because this water contains a sufficient amount of sediment to foul the bioreactor, the water is pre-treated with polyacrylamide (PAM) to flocculate soil particles; the pond water flows over tablets of polyacrylamide (PAM) and into a settling basin for approximately 40-60 minutes before entry into the bioreactor. During two periods of the summer (1 June-10 July and 14 Aug-24 Sept) alum (aluminum sulfate) was injected into the pond water as it entered the settling basin to test whether alum could reduce the water PO_4-P concentration by precipitation.

At all sites, the inlet and outlet flows of the bioreactors were continuously sampled by peristaltic pumps, with the sampled water stored in 20 gallon containers. Blended samples from those containers are collected for analysis 2-3 times per week during the crop production season (April-October). At site 3, grab samples of pond water were also collected so that the effectiveness of the PAM and alum treatments could be evaluated. The surface water bioreactor was deactivated at the end of October because insufficient irrigation was occurring to reliably provide runoff. The tile drain bioreactors (sites 1 and 2) were operated throughout the winter of 2011-12, with samples collected once per week for analysis.

Results

1. ***Treatment of tile drain and surface water to remove nitrate with denitrification bed reactor***

Water temperature at sites 1 and 2 fluctuated only modestly throughout the year, averaging approximately 61^{o}F during the summer, and 54^{o}F during the winter. Site 3 had substantially higher water temperature, averaging > 68^{o}F during the initial summer of operation. A high level of DOC was present initially in the outflow from all bioreactors, but declined to less than 20 PPM after several weeks of operation, only marginally higher than the incoming water. High DOC may stimulate the biological oxygen demand of the receiving waters. Additionally, tannins released by the wood chips darkened the water significantly in the initial weeks of operation. To minimize any adverse environmental effects arising from the operation of a bioreactor, the effluent from those initial weeks of operation might best be reapplied on the farm as pre-irrigation. Tile drain effluent presents a challenge in this regard due to high salt content, which ranged between 2-5 dS m^{-1} at sites 1 and 2; blending with a higher quality water source may be required.

At all sites, denitrification began within days of the initial filling of the bioreactors; denitrifying bacteria are ubiquitous, and ‘seeding’ of inoculum was not necessary. High initial denitrification rates slowed as the reactors matured, undoubtedly related to reduced carbon availability. Once the reactors at sites 1 and 2 reached a ‘steady state’ condition, denitrification rates averaged approximately 8 PPM NO_3-N per day of residence time during the rest of the 2011 irrigation season (July through October), and approximately 5 PPM during the winter of 2011-12 (Fig. 1). Denitrification rates from May through July, 2012, were similar to those achieved during the first summer of operation, suggesting long-term stability of performance. Equipment problems at both sites periodically resulted in more than 2 days of residence time; the mean daily denitrification rates cited above have been adjusted for those events.

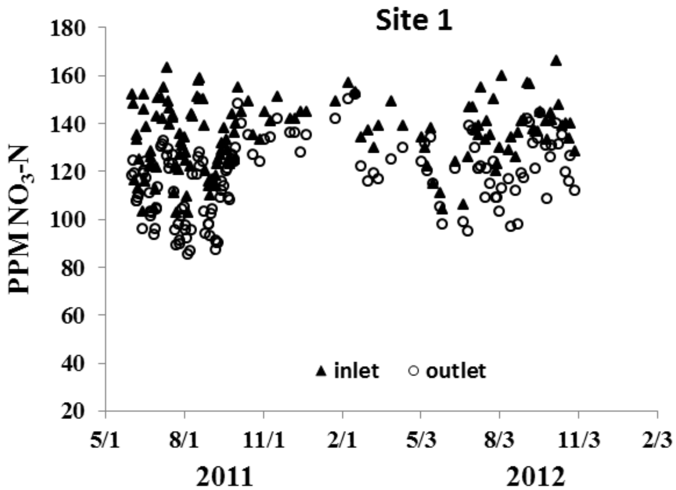
At site 3, the surface runoff pond water NO_3-N concentration ranged between 20-50 PPM (Fig. 2). Bioreactor treatment reduced NO_3-N concentration by an average of 14 PPM per day of residence time for the first three months of operation (June through August). Denitrification rate declined to an average of approximately 11 PPM NO_3-N per day of residence time from September through October, presumably due to reduced labile C availability and declining water temperature.

The runoff pond water ranged from 0.2-0.7 PPMPO_4-P. Injection of alum at 20 PPM, plus the time in the settling basin, reduced PO_4-P substantially (Fig. 3). Additional PO_4-P was removed in the bioreactor, with bioreactor effluent averaging < 0.1 PPM during the periods in which alum was injected. In the absence of alum, PO_4-P did not decline substantially in the settling basin, but was reduced by >50% on average during residence in the bioreactor. PAM treatment reduced the sediment content of water entering the bioreactor by approximately 97%. Denitrification rates observed in these bioreactors were similar to those reported in prior studies in which high NO_3-N water was remediated. The relative stability of performance of the bioreactors at sites 1 and 2 across years was also consistent with prior research, which has documented that wood chip reactors can remain functional for more than a decade. In spring, 2012, we had to add additional wood chips at these sites to keep them 'topped up', with no exposed water surface; this topping up required approximately 10-15% of the amount of wood chips initially required to fill the reactors.

The success of alum injection in reducing soluble PO_4-P was consistent with the success of this approach in municipal wastewater treatment. However, the decline in PO_4-P concentration in the bioreactor in the absence of alum injection was unexpected. Prior reports on wood chip bioreactors found little evidence of PO_4-P removal.

The lower initial NO_3-N concentration of surface runoff compared to tile drain effluent makes denitrification bioreactors more feasible for the treatment of surface runoff, provided that efficient sediment removal can be achieved. To be maximally effective, denitrification bioreactors would be only one element of an integrated irrigation and nutrient management system that minimizes both the volume and nutrient load of agricultural discharge.

Some preliminary cost evaluation of bioreactor remediation has been made. The wood chip media costs $35/ton, or approximately $9/cubic yard. Based on a blended average of the summer and winter denitrification rates achieved in this study, a bioreactor treating tile drain effluent could remove about 3 lb N per cubic yard of reactor volume per year. Assuming a 15% loss of chip volume per year, the media cost alone over the life of a bioreactor would be approximately $0.45 per lb NO_3-N denitrified. Costs of the original bioreactor installation (excavation, liner, wood chip hauling, etc.), loss of productive land, and operation and maintenance are currently being investigated. Other researchers have produced widely varying cost estimates of bioreactor performance, with the cost per pound of N denitrified varying from approximately $1-7. Our initial results suggest that costs for this technology in coastal California will likely be in the lower end of that range.



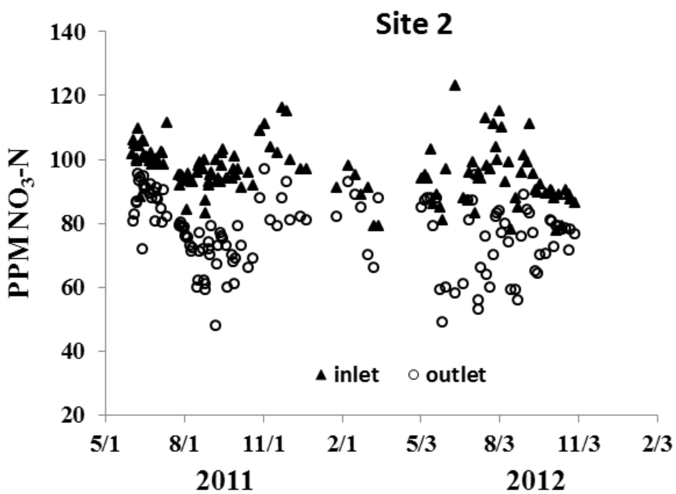


Figure 1. Reduction of water NO_3-N concentration during treatment in the denitrification bioreactors treating tile drain effluent.

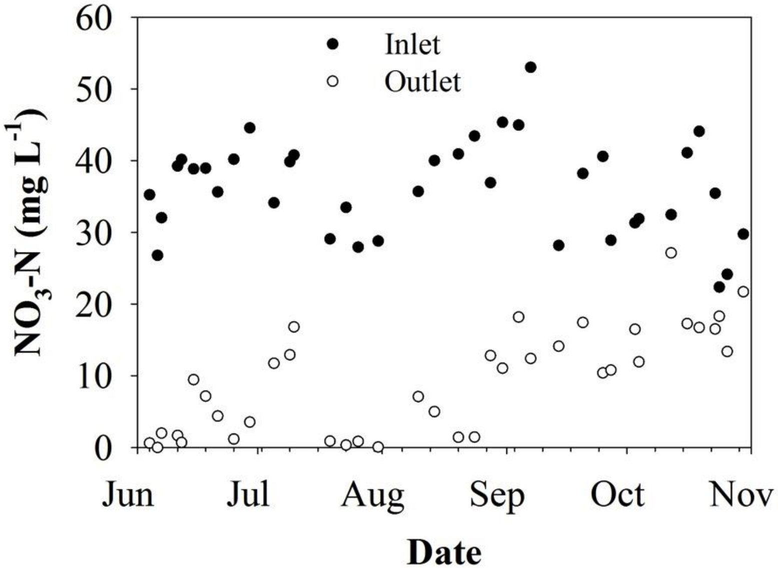


Figure 2. Reduction of water NO_3-N concentration during treatment in the denitrification bioreactor treating surface runoff (site 3).

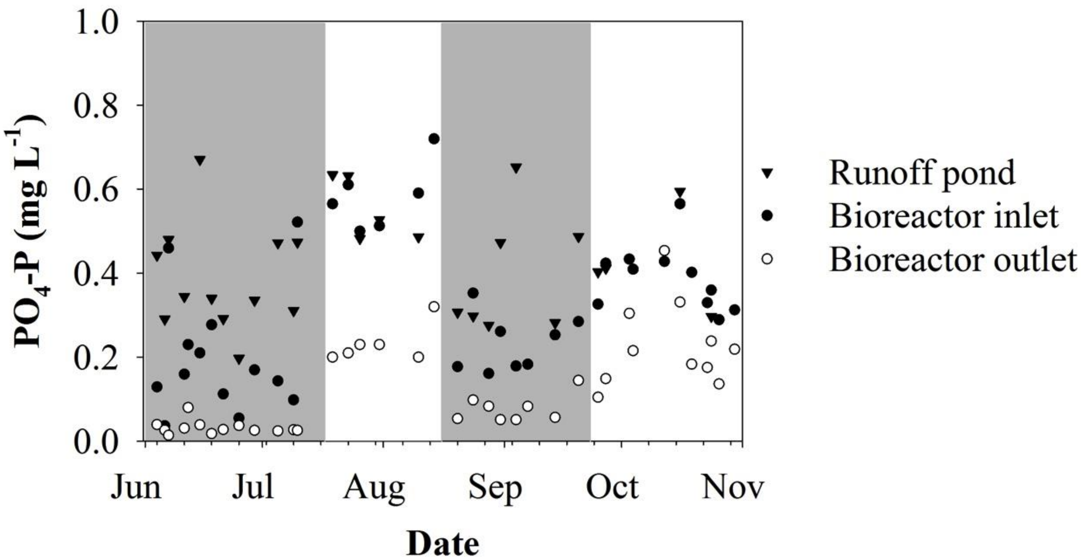


Figure 3. Effect of alum and bioreactor treatment on PO_4-P concentration of surface runoff water (site 3). Shaded areas represent periods during which alum was injected.

Procedures

2. ***Development of a nitrogen credit from prior crop***

Two soil incubation trials were conducted to determine the potential nitrogen contribution from mineralization of residues of lettuce, spinach and cauliflower after harvest. The release of mineral nitrogen (nitrate and ammonium-N) from the residue was measured over an 8-week period for the three crop residues as well as a no-residue control on sandy loam and clay loam soils. There were four replications of each residue/soil type combination. Soils were collected from commercial production fields, dried and screened (1/8" mesh), and moistened to field-capacity (20 kPa - including moisture from the residue). Five hundred grams of moist soil and crop residue (chopped into ¼ pieces) was placed in one-quart containers. Containers were incubated at 68-73 °F; soil samples were collected at 0, 2, 4, and 8 weeks and measured for mineral N by removing approximately ¼ of the soil in each container and analyzed for nitrate and ammonium-N. To calculate the net amount of N mineralized by crop residue, the quantity of N mineralized from unamended soil was subtracted from N mineralized by residue-amended soil. To calculate the quantity of N released by spinach, lettuce and cauliflower residue, the percent of mineralized N from crop residue in eight weeks was multiplied by the estimates of the N content of the residue typically remaining in production fields following commercial harvest.

Results

2. ***Development of a nitrogen credit from prior crop***

The three crop residues ranged from 3.1% N for cauliflower to 6.5% N for spinach with lettuce residue averaging 3.5% N (Table 1). Spinach residue contained 2.5% mineral N which is immediately available for plant growth of subsequent crops. Lettuce and Cauliflower had lower quantities of mineral N. Over the course of 8 weeks 67-83% of the N in the spinach residue mineralized; however, N mineralization by spinach had peaked by two weeks after incorporation into moist soil. 67-83% of the N contained in spinach residue mineralized over the 8 weeks of the evaluation releasing a total of 26-32 lbs N/A; Nitrogen release from spinach peaked at two weeks of indicating that this amount of N would be nearly immediately available to supply the N needs of the subsequent crop. Lettuce mineralized 51% of the N contained in its crop residue, which made about 35 lbs of N available to the subsequent crop as nitrate and ammonium. In these evaluations cauliflower residues mineralized from 36 to 65% of the N in the residue. It is unclear why this range was so wide but further evaluations are underway which may clear up this question. However, cauliflower residue contained from 220 to 280 lbs N/A and our data indicate that it mineralizes from 80 to 180 lbs N/A over eight weeks which can supply are large amount of the crop needs of a subsequent vegetable crop.

Table 1. Mineralization of N from post harvest residue of three vegetables.

Crop	Crop Residue Total N Percent	Crop Residue Mineral N Percent	Mineralization of organic N Percent	Total N in Crop Residue lbs N/A	N mineralized in 8 weeks (N credit) lbs N/A
Lettuce	3.49	0.74	51	70	35
Spinach	6.55	2.52	67-83	38	26-32
Cauliflower	3.10	0.31	36-65	220-280	80-180

Procedures

3. ***Survey of drip tape uniformity and impact on water and fertilizer distribution***

We evaluated the uniformity of applied water and fertilizer for surface placed drip in 11 commercial lettuce fields during the fall of 2012 and during the spring of 2013. All fields were planted with romaine or iceberg lettuce varieties on 40-inch or 80-inch wide beds. At each site irrigation, pressure, and fertilizer uniformity were evaluated during a single irrigation event. Field sizes ranged from 8 to 20 acres, and the maximum row lengths ranged from 600 to 1340 ft. Drip tape at all field sites was 7/8 inch diameter, medium flow tape (0.34 gpm/100 ft), but varied by manufacturer and age. The location where fertilizer was injected into the irrigation system, and start and end time of the fertigation, as well as the duration of the irrigation, were recorded. Before irrigating, couplers fitted with ¼ gallon per hour, pressure compensating emitters were spliced in to the drip tape at 24 locations within the field, representing the head, tail and middle areas. Water from these emitters was collected into 5 gallon containers during the entire irrigation and analyzed for NO_3-N and NH_4-N concentration. The discharge rate of 4 emitters and pressure of the tape was measured near each of the 24 fertilizer sampling locations (total of 96 emitters). Mass (lbs) of N applied at each of the 24 collection locations within a field was estimated by multiplying the measured discharge rate of the drip tape by the irrigation time and by the concentration of N in the collected water. Uniformity of applied water, tape pressure, and fertilizer was calculated by comparing the lowest 25% of measurements to the average of all 24 measurements. In addition to evaluating fertilizer distribution uniformity, we evaluated the time for fertilizer to travel to the furthest distance from the injection point by injecting food dye for a 5 minute period into the irrigation system and monitoring the water for color at the furthest point from the injection location.

Results

3. ***Survey of drip tape uniformity and impact on water and fertilizer distribution***

Distribution uniformity of applied water for the 11 fields averaged 73% and ranged from 38% to 88% (Table 2). The industry standard for irrigation uniformity of surface drip is 85%. Fertilizer application uniformity averaged 67% and ranged from 46% to 82%. Pressure uniformity averaged 80% and ranged from 43% to 99%.

Average pressures in the drip tape ranged from 3.5 to 13.8 psi (Table 3). Where the system pressure averaged 4.3 psi, the tape discharge rate was 30% less than the manufacturer's rating. Figure 4 shows that irrigation distribution uniformity decreased substantially when the average field pressure was less than 5 psi. Additionally, a substantial percentage of emitters of some drip systems were plugged (Table 3) which would reduce irrigation system uniformity. Leaks were evaluated in 5 fields and ranged from 1 to 5 leaks per 1000 ft of tape (Table 3). Significant leaks can potentially reduce drip uniformity by lowering the downstream pressure. Other limitations to good drip uniformity included mixing different types of tape in the same field, fluctuating pressure during the irrigation, and row lengths longer than 800 ft.

Field 8 had a high uniformity of pressure and irrigation distribution but a low fertilizer uniformity. We speculate that the fertilizer which was injected at a "T" connecting the valve in the field with the submain did not have sufficient time to mix with the irrigation water before the flow split into opposite directions. Hence, the average concentration of N on one side of the field was approximately half the concentration measured on the other side of the field. The distribution uniformity of fertilizer on individual sides of the fields was greater than 87%.

With the exception of field 8, fertilizer distribution uniformity was closely related with irrigation system uniformity. Fields with the lowest fertilizer uniformity were operated at the lowest average pressure and/or had the highest level of plugged emitters.
Fertilizer was injected at the well in 4 of the fields and at the submain valve in the other 7 fields (Table 4). Injections were made simultaneously using 2 valves at 3 of the fields. Fertilizer was injected during an average of less than 30 minute period often at the beginning of the irrigation (Table 4). The time required for the fertilizer to travel to the furthest point of the irrigation system averaged 42 minutes but ranged from as short as 22 minutes to as long as 1 hour. Field size, row length, and injection location appeared to affect the travel time of the fertilizer. The average time for flushing the fertilizer was 3.75 hours, which was ample time to allow the fertilizer to completely flush from the system. The irrigation industry recommends that for long irrigations (> 4 hours), fertilizer should be applied in the middle third of the irrigation. Only at field 10 was the fertilizer applied during the middle of the irrigation. The long flush periods could potential leach nitrate forms of fertilizer below the root zone of the crop. On average, half of the applied fertilizer N measured in the collection buckets was in the nitrate form.

This survey of commercial lettuce fields suggested that N fertilizer applied by fertigation is often not distributed to fields uniformly due to poorly operated or maintained drip systems. The highest distribution of fertilizer measured was 82%, but the average distribution of fertilizer was less than 70% for the 11 fields evaluated. Operation procedures observed at these sites would suggest that irrigators may need training to better understand the principles of fertigation so that they can achieve the potentially highest distribution of fertilizer, and to prevent losses of nitrate forms of fertilizer below the rooting depth of the crop.

Table 2. Summary of irrigation, fertilizer, and pressure uniformity of drip irrigated lettuce fields.

Field #	Lettuce Type	Bed width	Irrigation DU[1]	Fertilizer Uniformity	Pressure Uniformity
		inches	--------------	%	--------------
1	Romaine	40	58	54	82
2	Romaine	80	75	82	87
3	Romaine	80	81	73	62
4	Iceberg	40	80	75	89
5	Romaine	40	83	74	91
6	Romaine	80	46	66	79
7	Romaine	80	86	78	77
8	Iceberg	40	88	46	89
9	Romaine	80	38	32	43
10	Iceberg	80	81	80	86
11	Romaine	40	87	74	99
Average			73	67	80

[1]. Distribution Uniformity of the lowest quarter

Table 3. Drip tape characteristics at commercial lettuce sites.

Field	Distribution Uniformity	Tape re-use	Wall thickness	Emitter spacing	Average pressure	Plugged emitters	Tape leaks	Tape Discharge Rate measured	Tape Discharge Rate manufacturer
	%	# of crops	mil	inches	psi	%	#/1000 ft	----- gpm/100 ft -----	
1	58	15	8	8	7.2	5	--	0.28	0.34
2	75	>8	15	8	4.3	4	--	0.24	0.34
3	81	>3	10	12	8.3	1	--	0.34	0.34
4	80	10	10	8	13.8	2	--	0.42	0.34
5	83	10-11	10	8	10.8	3	--	0.41	0.34
6	46	4-5	10	8	4.6	16	--	0.24	0.34
7	86	3	10	8	7.0	2	0.8	0.31	0.34
8	88	12	10	8	9.0	0	4.3	0.39	0.34
9	38	2-3	9	12	3.5	2	0.4	0.23	0.34
10	81	4	8	12	7.2	3	3.4	0.23	0.34
11	87	3	10	12	12.4	0	5.4	0.43	0.34
Average	73		10		8.0	3	2.9	0.32	0.34

Table 4. Irrigation summary for drip systems.

Field	Lettuce Type	Travel time	Irrigation time	Injection time	Flush time	field size	Average row length	Max row length	Injection location
		-------------- hours:min			----------------	acres	------------- ft	-------------	
1	Romaine	1:04	5:20	0:23	4:30	8.0	610	620	well
2	Romaine	0:47	6:00	0:30	2:30	10.5	860	890	well
3	Romaine	0:40	7:00	0:20	4:20	20.2	940	1340	field, 2 valves
4	Iceberg	0:51	6:00	0:14	5:30	9.3	630	640	well
5	Romaine	0:22	6:00	0:13	5:00	8.7	530	640	field, 1 valve
6	Romaine	0:47	5:00	0:13	5:00	9.5	850	850	field, 1 valve
7	Romaine	0:40	6:00	0:22	3:00	8.5	600	675	field, 1 valve
8	Iceberg	0:41	5:20	0:19	2:30	10.6	685	800	field, 1 valve
9	Romaine	0:33	9:00	0:15	2:50	20.2	1030	1300	field, 2 valves
10	Iceberg	0:33	3:40	2:07	1:22	15.0	350	630	well
11	Romaine	0:47	5:00	0:13	5:00	18.3	575	600	field, 2 valves
Average		0:42	5:50	0:28	3:46	12.6	696	817	

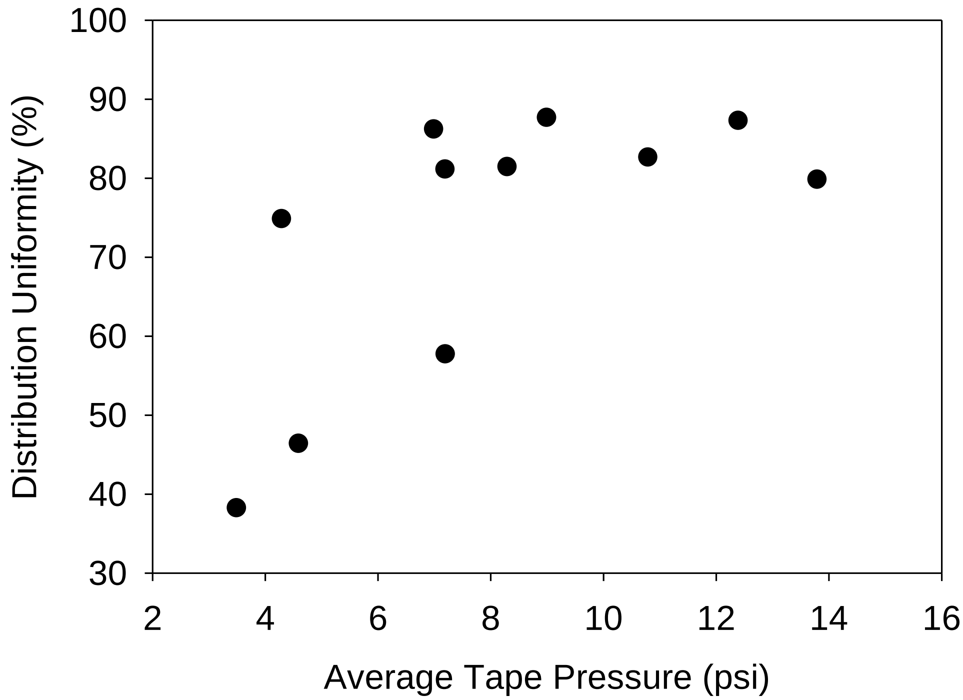


Fig. 4. Effect of tape pressure on the distribution uniformity of retrievable drip systems. Each symbol denotes a commercial lettuce field.

Procedures

4. Spinach nitrogen nutrition evaluations

Two trials were conducted in commercial first-crop spinach production fields. Trial 1 evaluated controlled release fertilizer (Duration 45 (D45) with a 'rapid' release pattern); trial 2 included D45 as well as nitrification inhibitors.Trials were conducted in commercial production fields with cooperating growers. All trials were conducted to "first crop" fields in order to have lower residual soil nitrate levels and improve the chances of getting a response to the fertilizer treatments. Trial 2 was cut short due to a communication mix up and the plot was accidentally topdressed two and a half weeks after the initiation of the trial. By the time of this mix up the season had progressed and there were no more first crop fields in the Salinas Valley with low residual soil nitrate that would be appropriate for a fertilizer trial.

Results

4. Spinach nitrogen nutrition evaluations

These fertilizer trials were conducted in first crop fields to find fields with lower levels of residual soil nitrate to improve the chances of response to the fertilizer treatments. In trial 1 the initial levels of residual soil nitrate were 20.8 ppm, but in spite of this high level, there was a good response to applied N in this field, as evidenced by the low yield of the untreated control. Soil nitrate levels in the untreated control, steadily declined over the crop cycle, while all other treatments maintained soil nitrate levels close to the initial level until the week of harvest. The preplant applications of 120 lbs N/A of D45 had yields equivalent to 182 lbs N/A in the standard treatment, 14.3 vs 12.7 tons/A, respectively (Table 2). 80 lbs N/A of D45 followed by 80 lbs

N/A of ammonium sulfate had good yields as well. Applying D45 preplant and mulching it into the soil gave better results applying it at planting and incorporating it with the seeding operation. The results of this trial were surprising. It was not clear if a controlled release material could provide nitrogen rapid enough to supply a crop like spinach with its high nitrogen demand during the last two weeks of the production cycle. This trial indicated that D45 was capable of releasing N quick enough to supply spinach; in addition, growers can use lower rates and achieve results comparable with the standard practice. Growers and crop production companies are following up on these results and conducting strip trials in commercial fields to further evaluate this material.

Trial 2 also included the nitrification inhibitor, DMPP; although this trial was cut short we observed that DMPP maintained a high level of ammonium-N in the soil for 18 days following the first germination water; this indicated that this material was inhibiting the transformation of ammonium to nitrate. The results from these trials indicate that controlled release fertilizers and nitrification inhibitors may have a role for use in spinach production and may be able to increase the nitrogen use efficiency.

Table 5. Spinach fertilizer trial No. 1. Yield and nitrogen uptake evaluation on June 4 (33 days after first water)

Pre-plant fert. & lbs N/A	At-planting fert. & lbs N/A	Top dress fert. & lbs N/A	Total lbs N/A	Yield fresh tons/A	Yield dry lbs/A	Tissue N percent	Tissue N lbs/A
120 D45[1]	0	0	120	14.3ab	2,474	5.5	136.5
80 D45	40	0	120	13.1bc	2,222	5.3	117.8
80 D45	0	80 AS	160	15.9 a	2,439	5.6	136.7
0	80 D45	80 AS	160	12.3bc	2,017	5.1	102.0
0	80 AS[3]	80 AS	160	13.1 b	2,176	5.0	108.9
120 D45	0	80 AS	200	15.1 a	2,316	5.9	135.9
0	0	0	0	6.8 d	1,382	3.1	43.1
87 U&AS[2]	0	95 AS	182	12.7bc	2,182	4.9	106.3
			Pr>F treat	<0.0001	<0.0001	<0.0001	<0.0001
			LSD $_{0.05}$	2.2	225	0.3	13.4

1 – Duration 45: Polyurethane coated urea (44% N); 2 – mixture of urea and ammonium sulfate – 29% N; 3 – Ammonium sulfate

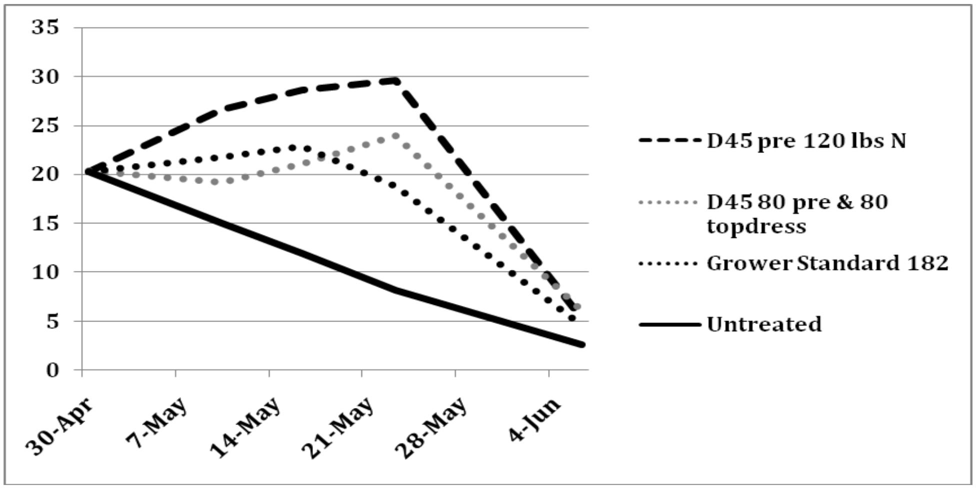


Figure 5. Soil nitrate-N levels in four selected treatments from spinach fertilizer trial No. 1