A. Project Information
Final Report
FREP Project 11-0558-SA

Survey of Nitrogen Uptake and Applied Irrigation Water in Broccoli, Cauliflower and Cabbage Production in the Salinas Valley

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B. Objectives:

1. Evaluate nitrogen (N) uptake, water application and rooting depth of broccoli, cauliflower and cabbage
2. Extend the findings of this research to growers on the Central Coast to increase understanding of N uptake and publish results to provide documentation of the findings

C. Abstract

This project was originally designed to evaluate the uptake of N, water use and rooting depth of broccoli, cauliflower and cabbage. However, we observed that broccoli and, to a lesser extent, cauliflower and cabbage take up greater quantities of N than are applied as fertilizer. Evaluations of the quantity of N available down to two feet deep in the soil in broccoli fields grown after lettuce indicated that there may be sufficient quantities of N in the second foot of soil that may partially provide for the needs of cole crops. We measured cole crop roots down to 36 to 48 inches deep which may indicate that they are accessing nitrate deeper in the soil profile than more shallow rooted crops such as lettuce and spinach. In this sense, cole crops are retrieving N from the soil and bring it back to the soil surface, thereby making it available for subsequent crops to access once crop residues decompose. These observations are helping us to think of how we can use cole crops as a best management practice (BMP) to help mitigate nitrate leaching in intensively managed cool season vegetable rotations. This project also observed that the growers that were surveyed generally applied water in excess of the evaporative needs indicating that leaching may occur. Clearly improvements in irrigation management can help improve the important role that cole crops play in scavenging excess nitrate from the soil profile. As a result of this project, we have included an option in the CropManage web-based

decision support program for nitrate levels in the second foot of soil to help better manage N applications to broccoli.

D. Introduction

Water quality regulations passed by the Central Coast Regional Water Quality Control Board (CCWQCB) require growers to monitor and implement practices to improve the efficiency of applied nitrogen (N) to vegetable crops. The proposed regulations focus on nitrate loss in vegetable and other horticultural crops and in 2014 will begin to require reporting of the quantity of N applied vs the quantity of N taken up by the crop.

The regulations create the need for N uptake data for a variety of crops. Various commodity boards have funded research to address N uptake by specific commodities: There are other key commodities grown on the Central Coast that do not have support of commodity boards such as broccoli, cauliflower and cabbage. In 2009, there were 85,287 acres of broccoli, 24,334 acres of cauliflower and 6,568 acres of cabbage in the counties included in the CCRWQCB with a combined total value of $651,089,618. This project was undertaken to determine the nitrogen uptake and water use by broccoli, cauliflower and cabbage.

E. Work Description

The project consists of a survey of well-managed, high-yielding broccoli, cauliflower and cabbage fields in Monterey County. Thirty-eight evaluations were completed from 2012 to 2014; four evaluations of broccoli and cauliflower during the winter of 2012-13, and all other evaluations were conducted during the summers of 2012 to 2014. Fields were selected that had production practices typical for this region (i.e. direct seeded broccoli; transplanted cauliflower and cabbage); however, new configurations are being utilized by growers and some of these were also included in the evaluations (5-line broccoli, 3 line cauliflower, and 5 line cabbage on 80 inch beds). Irrigation and fertilization practices of selected fields were also typical of the region. Fields were selected that encompass the range of microclimatic factors (e.g. Castroville to King City) and diverse soil types (sandy loams to clay loams). Crop biomass, biomass N and soil nitrate-N were measured three to four times during the growing season to measure the N uptake pattern and total N uptake. Biomass samples were collected by collecting a quantity of plants (4 to 20) or plants from a strip of bed (e.g. 10 feet) at random from four parts of the field in at each evaluation; the number of plants surveyed depended on the size of the plants. At harvest, total biomass and commercially harvested biomass and biomass N were measured. Also, at harvest, total crop biomass was also analyzed for phosphorus and potassium. Fertilizer application rates and timing in each field were also recorded.

Rooting depth of the crops was measured at weekly intervals during plant establishment and then bimonthly intervals until harvest. We excavated plants in

3 locations within the field to identify the depth of deepest roots. Pits were dug near harvest in one field of each commodity per year to expose a cross-section of the bed and map out the final root distribution. Rooting depth evaluations were initiated in the spring of 2012 and completed in June 2014.

Flow meters were installed at each monitored field to quantify the volume of water applied from crop establishment to harvest. The flow meters were connected to data loggers to record the length and frequency of irrigations. Infra-red canopy photos were taken every 2 weeks to develop crop coefficients for estimating crop ET. Soil moisture sensors were installed to monitor changes in soil moisture storage. This data provided an estimate the volume of drainage below the root zone. Irrigation evaluations were completed in June 2014.

F. Data/Results

Nitrogen Uptake: *Summer Evaluations:* Broccoli, cabbage and cauliflower took up about 337.4, 284.4 and 354.6 lbs N/A, respectively in the above ground biomass (Table 1). Cabbage had the highest N content in the harvested portion of the biomass at 180.3 lb N/A; 99.3 and 66.6 lbs N/A were removed in the harvested biomass of broccoli and cauliflower, respectively. Applied fertilizer averaged 181.9, 220.8 and 249.8 lbs N/A for broccoli, cauliflower and cabbage, respectively. Subtracting the quantity of N applied to the crops from the amount taken up indicated that each of these crops scavenged N from the soil. In these surveyed fields, the amount of N scavenged by broccoli, cauliflower and cabbage was 155.5, 63.6 and 104.8 lbs N/A, respectively.

Cabbage produced the highest overall biomass per acre (11,976.2 lbs/A) followed by broccoli (8,585.8 lbs N/A) then cauliflower (6,865.6 lbs N/A) (Table 2). The high percent of N in the tissue coupled with the high biomass production by these crops creates the high N uptake. The concentration of N in the overall biomass at harvest for broccoli, cauliflower and cabbage at harvest was 4.0, 4.1 and 3.0 %N, respectively. Potassium (K) concentrations in the plant tissue was equal to or higher than N in all three crops, and the concentration of phosphorus (P) ranged from 0.37 to 0.65%.

Given the disparity in the amount of N applied to broccoli vs the amount taken up we decided to sample the soil down to two feet to see if we could better understand the source of the additional N. On average, at the 1-2-foot depth, there was a substantial quantity of N at the beginning of the crop cycle through midgrowth (Table 3). These evaluations may help explain why broccoli takes up more N than is routinely applied.

Winter Evaluations: Broccoli and cabbage took up about 249 lbs N/A and cauliflower 273 lbs N/A (Table 4). 94 and 70 lbs of N were removed in the harvested biomass for broccoli and cauliflower, respectively. Broccoli and cauliflower had 272 and 351 lbs N/A applied, respectively. Nitrogen scavenging was not observed in broccoli and cauliflower in winter production in the fields surveyed. Fertilizer applied to broccoli was about even with the quantity applied and fertilizer N applied to cauliflower exceeded uptake by 78 lbs/A.

Total biomass production by broccoli was 5,539 lbs/A, and cauliflower was 6,490 lbs/A (Table 5). Broccoli plants were much smaller in the winter, but biomass production by cauliflower was only slightly less than in the summer. Both total potassium uptake and concentration in the tissue were less in the winter than in the summer for both crops.

Nitrogen uptake pattern of cole crops: The pattern of crop N uptake of broccoli, cauliflower, and cabbage followed a sigmoidal pattern and can be described mathematically by eqn. (1):

$$\text{N uptake (lbs/acre)} = a \times Nmax/(1+\exp[\,(-(day/Maxday)-Yo)/b]\,) \qquad (1)$$

Where *Nmax* is the amount of N (lbs/acre) that the crop accumulates in the above ground biomass at harvest, *a, b,* and *Yo* are fitted parameters, *day* is the number of days after planting and *Maxday* is the average length of the crop cycle, calculated as the days between planting and harvest. Fitted parameters for eqn (1) are summarized in Table 3. These parameters were added to CropManage so that users can estimate the N needs of cole crops.

Winter and summer crops of broccoli (Figs. 1 and 2) and cauliflower exhibited different patterns of N uptake. Summer crops accumulated approximately 20% of the total nitrogen during the last 20% of the growing season. In contrast, winter crops accumulated 70% of total N during the same period. The delay in N uptake of winter crops was likely related to the low temperatures and short days that slowed crop growth during early winter. The rate of N uptake presumably increased in late winter (February –March) when average air temperature and day length increased.

Canopy cover evaluations: Canopy cover of cole crops was measured by taking overhead photos at 10 to 15-day intervals during the crop cycle using a near-infrared multispectral camera. Canopy cover data (Fig. 3) were fit to a developmental model proposed by Gallardo et. al. (1996):

$$\text{Canopy cover (\%)} = Gmax/(1 + \exp[A + B \times day/(Maxday*Fmax)] \qquad (2)$$

where Gmax is the maximum canopy cover, *A* and *B* are fitted parameters, day is the number of days after planting or transplanting, *Maxday* is the total days between planting and the end of the crop (last harvest), and *Fmax* is the fraction of the crop cycle when the maximum canopy size is achieved. Parameters for this model were determined for broccoli, cabbage, and cauliflower grown under various planting configurations (Tables 7, 8 & 9). These models were added to CropManage so that growers can estimate the water use of their crops using

CIMIS reference ET data and a crop coefficient (Kc) calculated using the equation:

$$Kc = (0.63+1.5\ C - 0.0039C^2)/100 \qquad (3)$$

where Kc is the crop coefficient, ranging approximately between 0 and 1.0, and C is percent canopy cover estimated in equation 2. Equations 2 and 3 were used to estimate crop ET for the cole crop fields that were monitored during this study.

Water use: The average volume of water applied to broccoli, cabbage and cauliflower was 21.6, 24.0 and 22.2 inches, respectively and the average crop ET was 9.0, 11.2 and 7.8 inches, respectively (Table 10). Interestingly, applied water and estimated crop ET for transplanted broccoli and cabbage was greater than for direct seeded crop. Presumably, higher ET and applied water for transplanted crops was a result of extra sprinkler irrigations needed to establish transplants and because transplanted crops may have reached full canopy (100% cover) earlier in the crop cycle than direct seeded crops.

Soil moisture: Soil moisture tension was monitored using watermark granular matrix sensors in 5 broccoli and 2 cauliflower fields after establishment (between first side-dress and harvest). Both the broccoli and cauliflower fields were irrigated with overhead sprinklers or a combination of sprinklers and surface drip. Soil moisture tensions ranged from < 10 cbars to > 150 cbars, indicating that these crops often depleted much of the available soil moisture between irrigations, independent of irrigation method (Fig. 4). Low soil moisture tensions (< 30 cbars) represented 50% to 60% of the crop cycle for broccoli and cauliflower (Figs. 5 and 6). Soil moisture tensions greater than 60 cbars represented 24% and 19% of the crop cycle for the 12- and 24-inch depths, respectively, for cauliflower, and 34% and 17% of the crop cycle for the 12 and 24 inch depths, respectively, for broccoli.

Rooting Patterns: Root distribution was evaluated in commercial fields when the crop reached maturity by excavating cross-sections of the beds to a 42-inch depth. Soil was washed away from the soil profile to expose roots and a 10 cm ×10 cm grid was overlaid on the soil profile to facilitate counting the roots per 100 cm^2 at varying depths and lateral distances from the plant rows. Soil was also sampled from these same locations to evaluate the distribution of soil nitrate in the soil.

A majority of roots were measured within the upper 2 feet of the soil profile (Figs. 7-9). However, roots were measured as deep as 40 inches. In broccoli roots were proportionally higher in the top foot for 80-inch beds (Figure 8, field 3). Cross-sectional distribution measurements of roots also indicated that roots are mainly located in the upper 2 feet of the soil profile with the greatest density under the plant row in the upper foot of depth (Figs. 10 and 12). Soil nitrate concentration in the soil profile was lowest in the upper 2 feet at the end of the season (Figs. 11 and 13). Higher residual soil nitrate concentrations were measured deeper than 2 feet where the root density of both broccoli and cabbage were lowest.

Root development: Rooting depth of broccoli, cabbage, and cauliflower increased linearly with time during the crop cycle, reaching maximum depths near the time of harvest (Figs. 14 – 16). The rooting depth of Cole crops was generally less than 10 inches during the first 20% of the crop cycle. Broccoli and cauliflower roots reached a maximum depth of 36 inches and cabbage roots reached a maximum depth of 31 inches. At some sites, broccoli and cauliflower roots reached a maximum depth of 48 inches. Root development patterns were generally consistent across different soil types, locations, and seasons. These data are useful for understanding the depth from which these crops extract water and nutrients at different stages of development. The rooting depth data was incorporated into algorithms used in CropManage for estimating water needs of Cole crops.

Table 1. Summers 2012 to 2014. Above ground N/A in crop, yield components, applied fertilizer, N scavenged from soil and N in residue at harvest

Crop[1]	Total uptake N/A (SE)	Heads Harvested N/A (SE)	Leaves Unharvested N/A	Stalks Unharvested N/A	Roots N/A	Fertilizer applied N/A	Scavenged from soil N/A	Unharvested residue N/A
Broccoli	337.4 (20.2)	99.3 (8.4)	197.6	40.5	11.4	181.9	155.5	238.1
Cauliflower	284.4 (7.9)	66.6 (3.7)	197.2	19.9	9.3	220.8	63.6	217.8
Cabbage	354.6 (22.8)	180.3 (13.1)	174.3	---[2]	10.3	249.8	104.8	174.3

1 – Broccoli n=10; cauliflower n=5; cabbage n=10; 2 – leaves and stalks are combined for cabbage in leaves column

Table 2. Summers 2012 & 2013: Biomass, and content of N, P and K in total biomass at harvest of Cole crops

Crop	Fresh biomass Lbs/A	Dry biomass Lbs/A	% Solids whole plants	%N total biomass (SE)	%P Total biomass	%K Total biomass	Total P uptake lb/A	Total K uptake lb/A
Broccoli	94,213	8,585.5	9.2	4.0 (0.2)	0.52	4.20	44.7	360.2
Cauliflower	88,307.1	6,865.6	7.8	4.1 (0.1)	0.65	4.02	42.3	277.0
Cabbage	145,252.9	11,976.2	8.3	3.0 (0.1)	0.37	3.10	43.7	362.4

Table 3. Parameters for model (eqn. 1) of N uptake pattern of Cole crops.

		fitted parameters of equation (1)								
Crop	Season	A	b	Yo	N uptake at harvest (Nmax)	Crop cycle (Maxday)	Sites	Years	R^2	p-value
					lbs N/acre	days	#			
broccoli	Winter	2.2050	0.1480	1.0274	249	139	4	2012, 2013	0.99	<0.0001
broccoli	summer	1.0835	0.1292	0.6968	337	86	10	2012, 2013	0.99	<0.0001
cauliflower	summer	1.0623	0.1306	0.6519	283	74	6	2012	0.95	<0.0001
cauliflower	Winter	1.5309	0.1446	0.9087	274	127	4	2012	0.98	<0.0001
red cabbage	summer	1.0346	0.1416	0.6080	386	90	3	2012	0.95	<0.0001
green cabbage	summer	1.0411	0.1354	0.6429	317	76	7	2012, 2013	0.95	<0.0001

Table 4. Average nitrate in the soil at five growth stages for each crop.

	Depth	Mineral N	Baseline	Early growth	Mid-growth	Late growth	Harvest
Broccoli	1st foot	NO_3-N	46.5	23.3	12.1	8.3	6.1
	1st foot	NH_4-N	2.3	2.2	2.1	2.1	1.8
	2nd foot	NO_3-N	29.2	48.9	27.8	12.5	5.1
	2nd foot	NH_4-N	1.1	1.4	1.5	1.13	1.4
Cauliflower	1st foot	NO_3-N	83.9	35.7	17.5	23.4	12.2
	1st foot	NH_4-N	12.6	7.32	2.3	9.0	3.3
Cabbage	1st foot	NO_3-N	42.0	13.1	8.1	3.3	7.9
	1st foot	NH_4-N	1.4	1.3	2.0	1.5	2.1

Table 5. Winter 2012-13 Evaluations. Above ground lbs of N/A in crop, yield components, applied fertilizer, N scavenged from soil and N in residue at harvest

Crop[1]	Total uptake Lbs N/A	Heads Harvested Lbs N/A	Leaves Unharvested Lbs N/A	Stalks Unharvested Lbs N/A	Roots Lbs N/A	Fertilizer applied Lbs N/A	Uptake-Applied Lbs N/A	Unharvested residue Lbs N/A
Broccoli	249.5	93.9	128.0	28.7	7.7	272.7	-23.2	155.6
Cauliflower	273.7	70.2	160.3	14.1	8.6	351.7	-78.1	174.5

1 – Broccoli n=4; cauliflower n=4

Table 6. Winter 2012-13 Evaluations. Biomass, and content of N, P and K in total biomass at harvest of Cole crops

Crop	Fresh biomass Lbs/A	Dry biomass Lbs/A	% Solids whole plants	%N total biomass	%P Total biomass	%K Total biomass	Total P uptake lb/A	Total K uptake lb/A
Broccoli	57,922	5,539.2	10.0	4.5	0.58	3.35	32.4	194.1
Cauliflower	72,464	6,490.5	9.0	4.2	0.56	3.69	36.4	236.0

Table 7. Canopy cover model parameters for broccoli.

Crop description	number of sites	bed width	seedlines	Crop Cycle	Model Parameters A	B	Gmax	Fmax	Model fit R^2
	#	inches	#	days			%		
Winter, direct seeded	3	40	2	137	5.39	-7.70	89	0.96	0.87
Summer, direct seeded	6	40	2	87	6.51	-10.82	98	0.78	0.91
Summer, transplanted	1	80	5	87	5.35	-11.13	99	0.91	0.97
Summer, transplanted	2	40	2	87	3.34	-7.83	99	0.93	0.95

Table 8. Canopy cover model parameters for cabbage.

Crop description	number of sites	bed width	seedlines	Crop Cycle	Model Parameters A	B	Gmax	Fmax	Model fit R^2
	#	inches	#	days			%		
Summer, green, seeded	2	40	2	77	6.54	-10.96	95	0.81	0.80
Summer, green, transplanted	2	40	2	77	4.64	-9.69	98	0.81	0.93
Summer, green, transplanted	2	80	5	77	4.74	-10.45	87	0.79	0.95
Summer, red, transplanted	4	40	2	89	3.93	-8.09	99	0.65	0.89

Table 9. Canopy cover model parameters for cauliflower.

Crop description	Number of sites	Bed width	Plant lines	Crop Cycle	Parameters (eqn. 2) A	B	Gmax	Fmax	Model fit R^2
		inches	#/bed	days			%		
Summer, TP[x]	3	40	1	72	4.62	-8.63	91	0.95	0.83
Summer, TP	1	40	2	75	4.34	-9.25	98	1.00	0.91
Summer, TP	3	80	3	77	5.63	-9.35	94	0.87	0.92
Winter, TP	1	40	2	126	4.88	-8.42	90	1.00	0.94
Winter, TP	3	40	1	128	3.87	-6.27	66	0.93	0.94
Winter, TP	1	80	3	127	4.87	-6.83	95	1.00	0.94

[x]Transplanted

Table 10. Applied water to broccoli, cabbage and cauliflower

Crop	Establishment method	Number of Fields	Average Applied Water and Rainfall			Average Crop ET
			Total	Irrigation Water	Rainfall	
			---------------- inches ----------------			
Broccoli	Seeded	11	21.2	19.0	2.2	8.6
	Transplant	3	23.1	21.0	2.1	10.4
	All methods	14	21.6	19.4	2.2	9.0
Cabbage	Seeded	2	21.3	21.1	0.2	10.7
	Transplant	9	24.7	24.5	0.2	11.3
	All methods	11	24.0	23.8	0.2	11.2
Cauliflower	Transplant	11	22.2	20.0	2.2	7.8

Table 11. Estimated drainage and leaching losses of NO3-N for broccoli, cabbage, and cauliflower, assuming a silt loam soil (20% sand, 55% silt) and an average soil nitrate concentration of 15 ppm NO3-N during the season.

Crop	Applied Water and Rainfall	Crop ET	Soil Moisture Storage	Total Drainage	Average Soil NO_3-N	Estimated N loss[x]
	-------------------- inches --------------------				ppm	lbs N/acre
Broccoli	21.6	9.0	-0.5	13.1	15	133
Cabbage	24.0	11.2	-0.5	13.3	15	135
Cauliflower	22.2	7.8	-0.5	14.9	15	152

[x] estimated leaching losses below 2 ft.

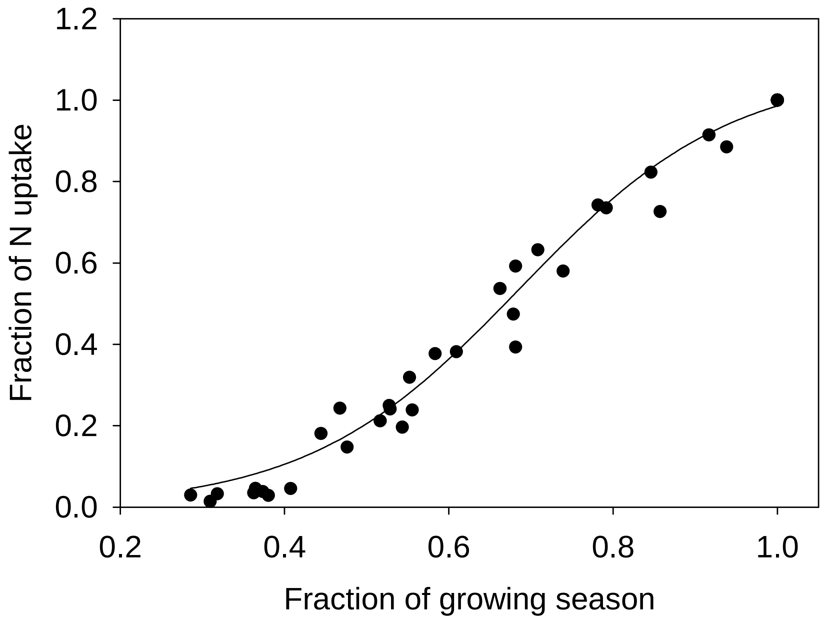

Figure 1. N uptake pattern of summer-harvested broccoli.

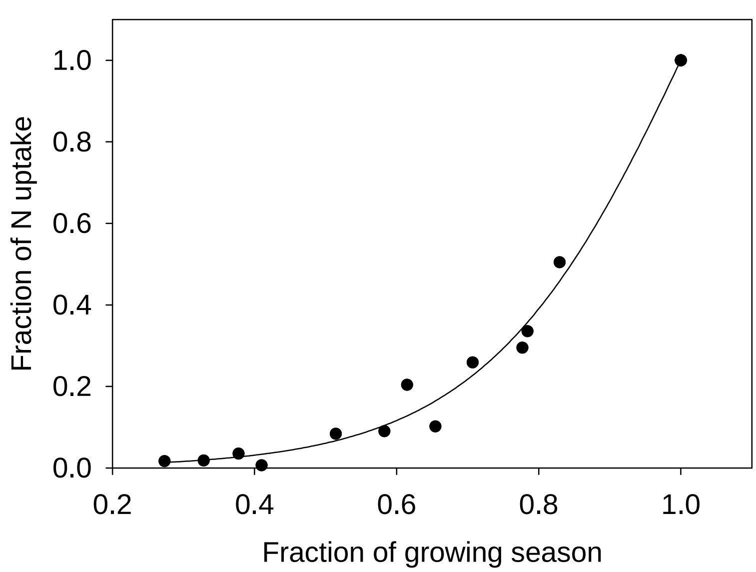

Figure 2. N uptake pattern of winter-harvested broccoli.

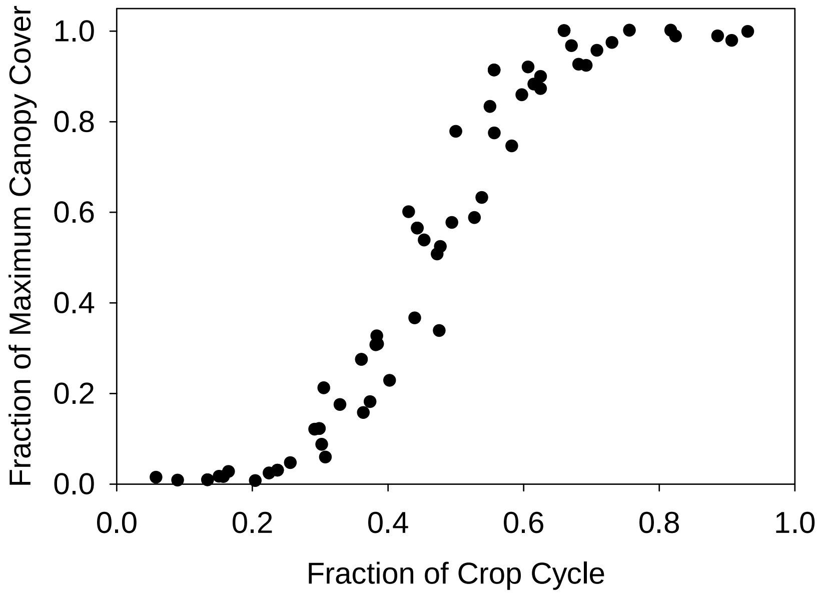

Figure 3. Canopy development of summer planted broccoli expressed as a fraction of maximum cover.

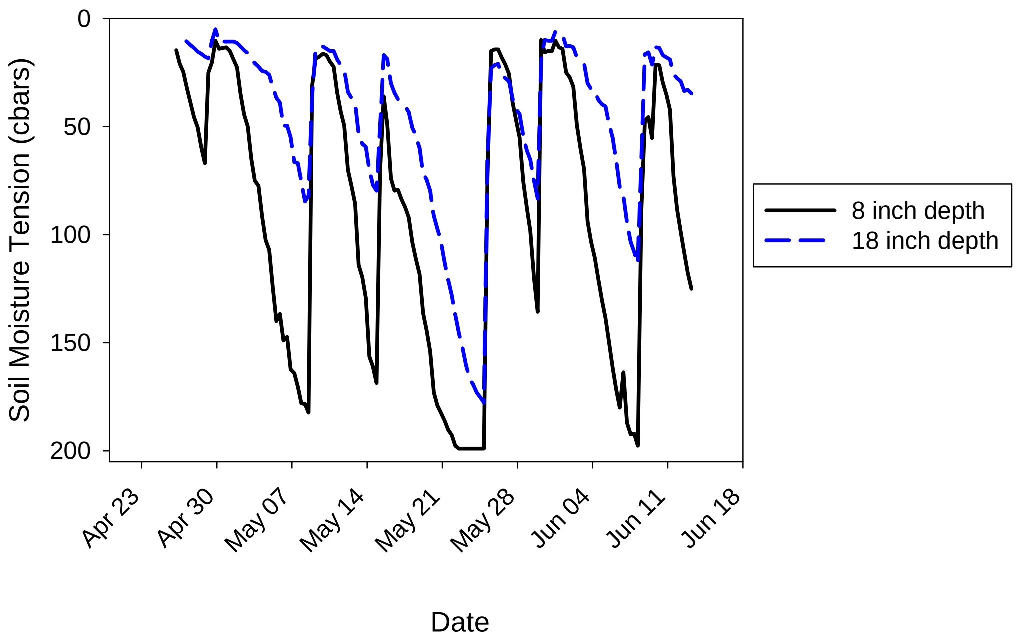

Figure 4. Soil moisture tension measured with watermark blocks at 8- and 18-inch depths in a commercial broccoli field.

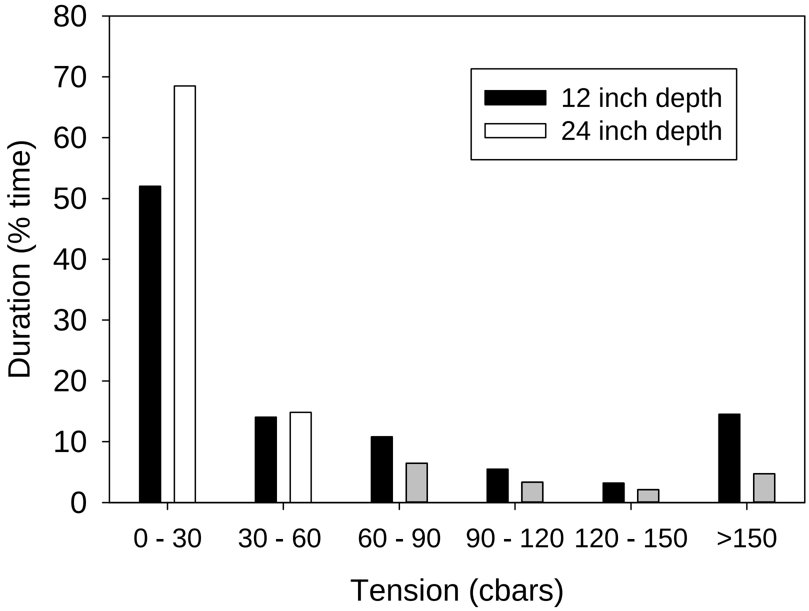

Figure 5. Duration of time at various ranges of soil moisture tension between post-establishment and harvest of broccoli (5 fields).

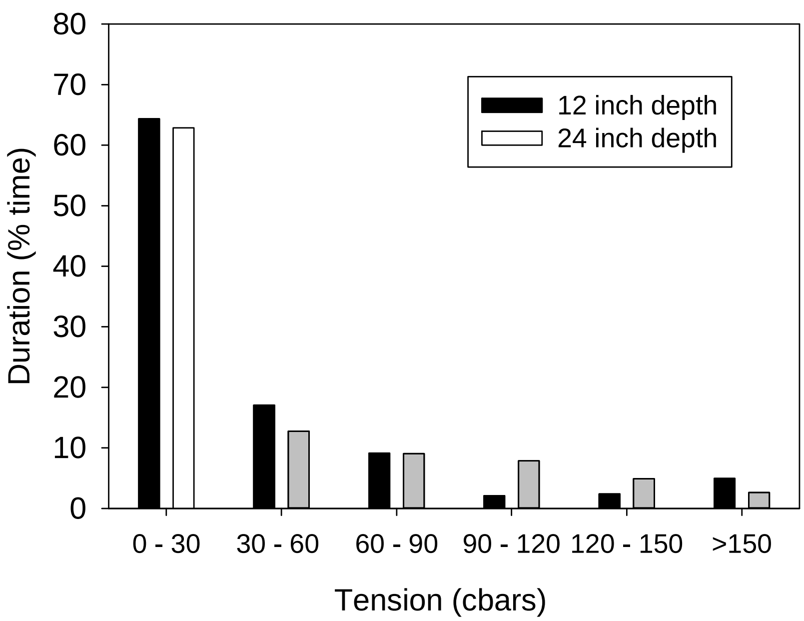

Figure 6. Duration of time at various ranges of soil moisture tension between post-establishment and harvest of cauliflower (2 fields).

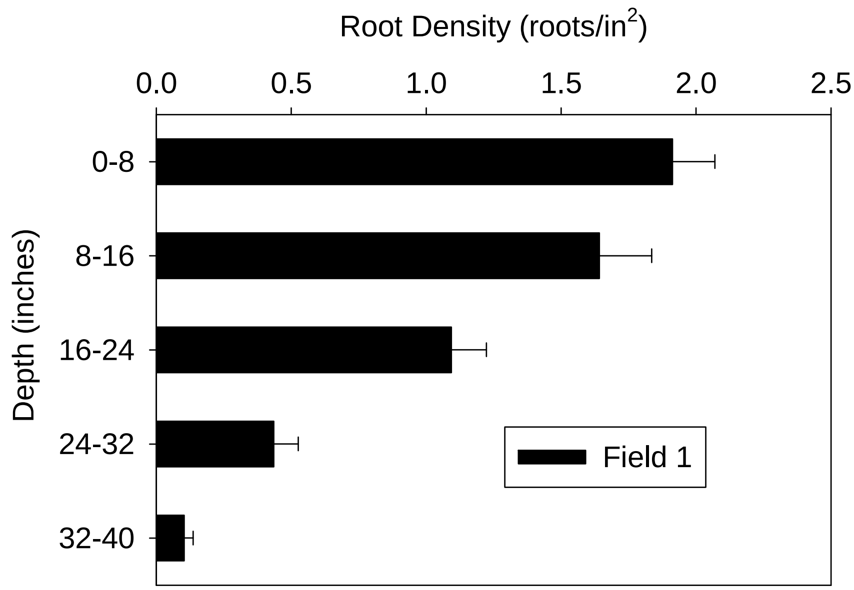

Figure 7. Rooting distribution with depth for cabbage evaluated in a commercial field at harvest.

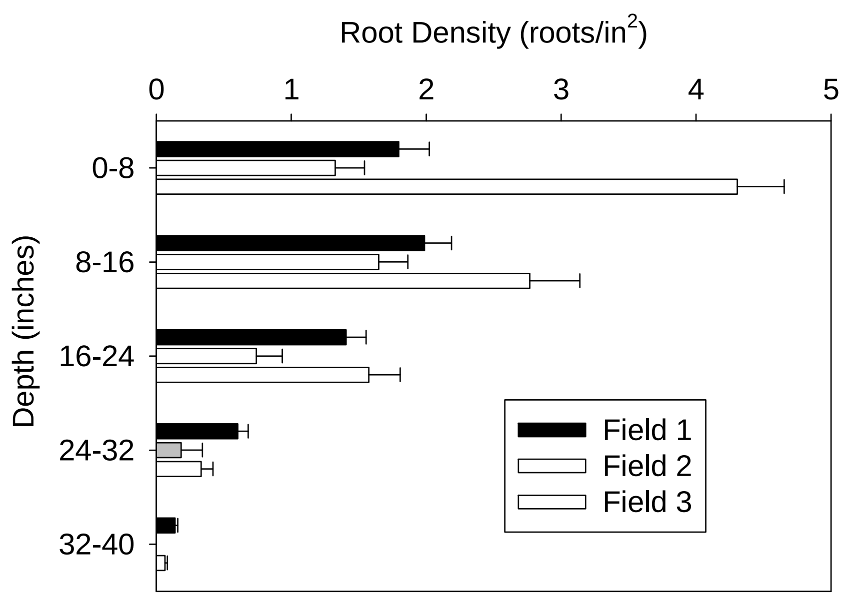

Figure 8. Rooting distribution with depth for broccoli evaluated in 3 commercial fields at harvest. Fields 1 and 2 were 40-inch-wide beds and field 3 was 80 inches wide.

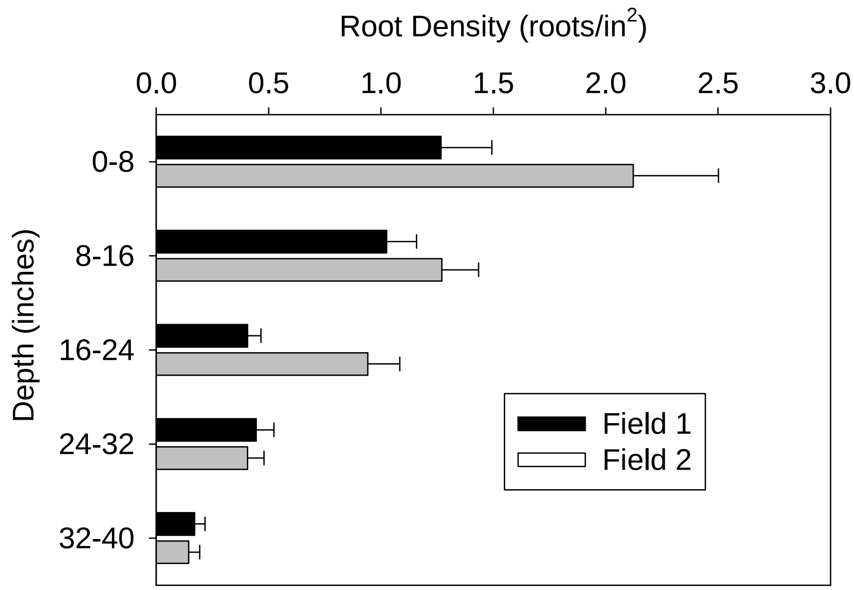

Figure 9. Rooting distribution with depth for cauliflower evaluated in 2 commercial fields at harvest.

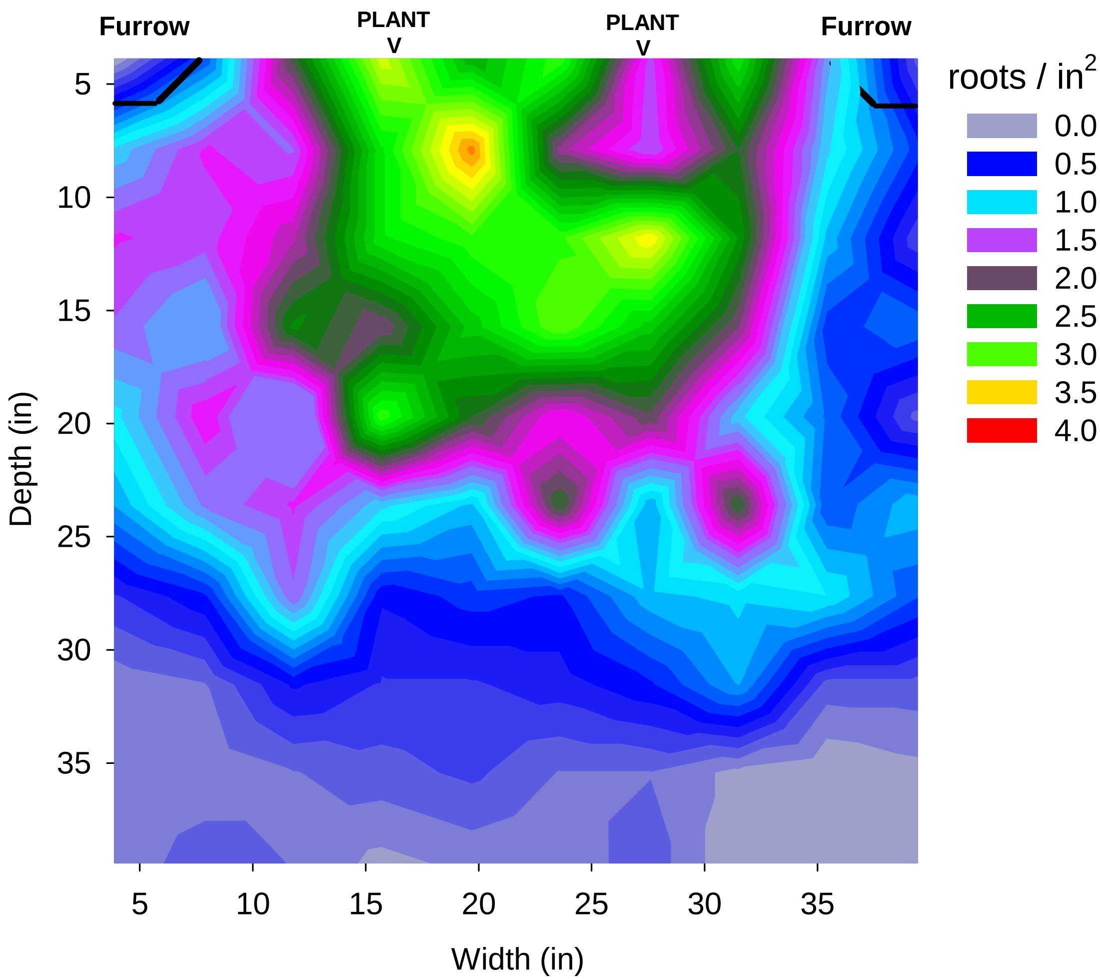

Figure 10. Cross-sectional distribution of roots of broccoli, commercially grown on 40-inch wide beds. Arrows indicate location of plant rows.

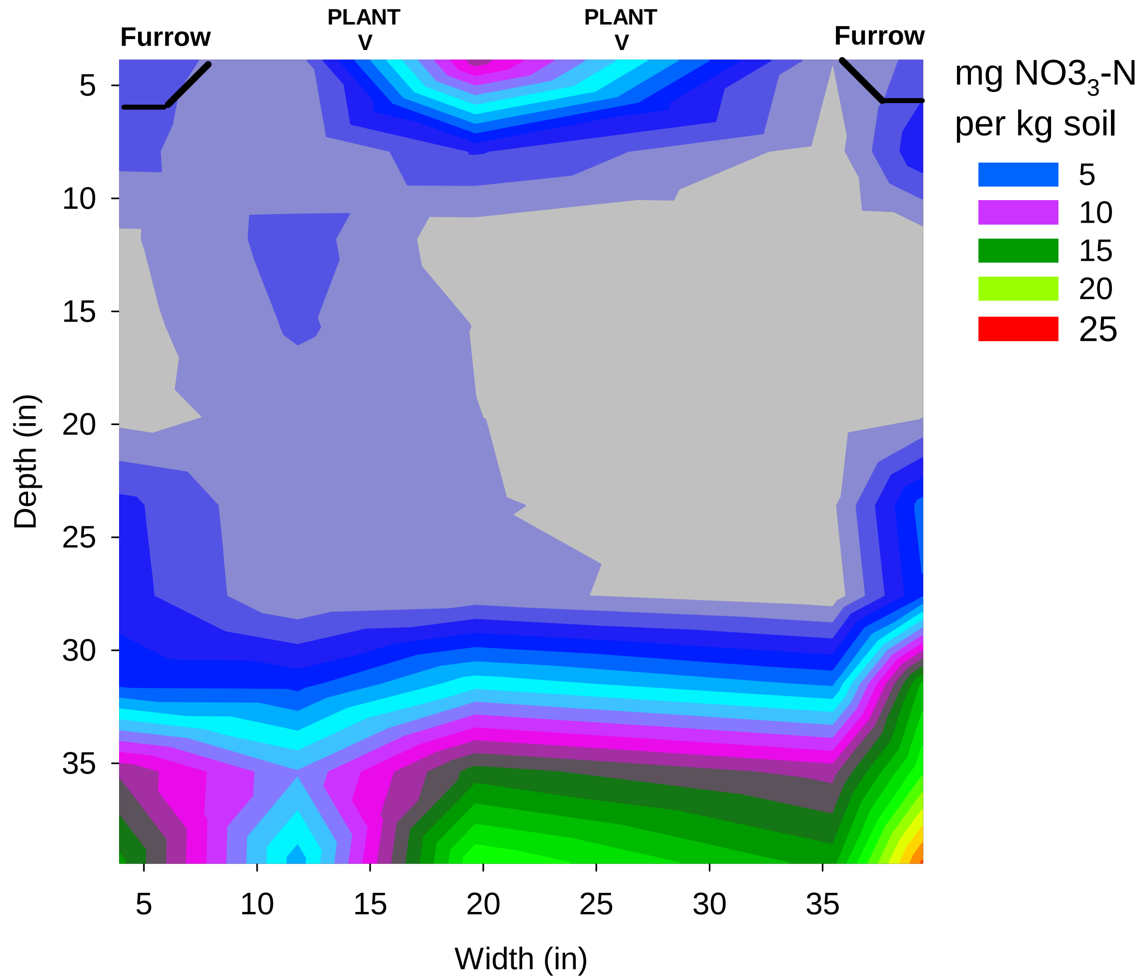

Figure 11. Cross-sectional distribution of soil NO_3-N for broccoli, commercially grown on 40-inch wide beds. Arrows indicate location of plant rows.

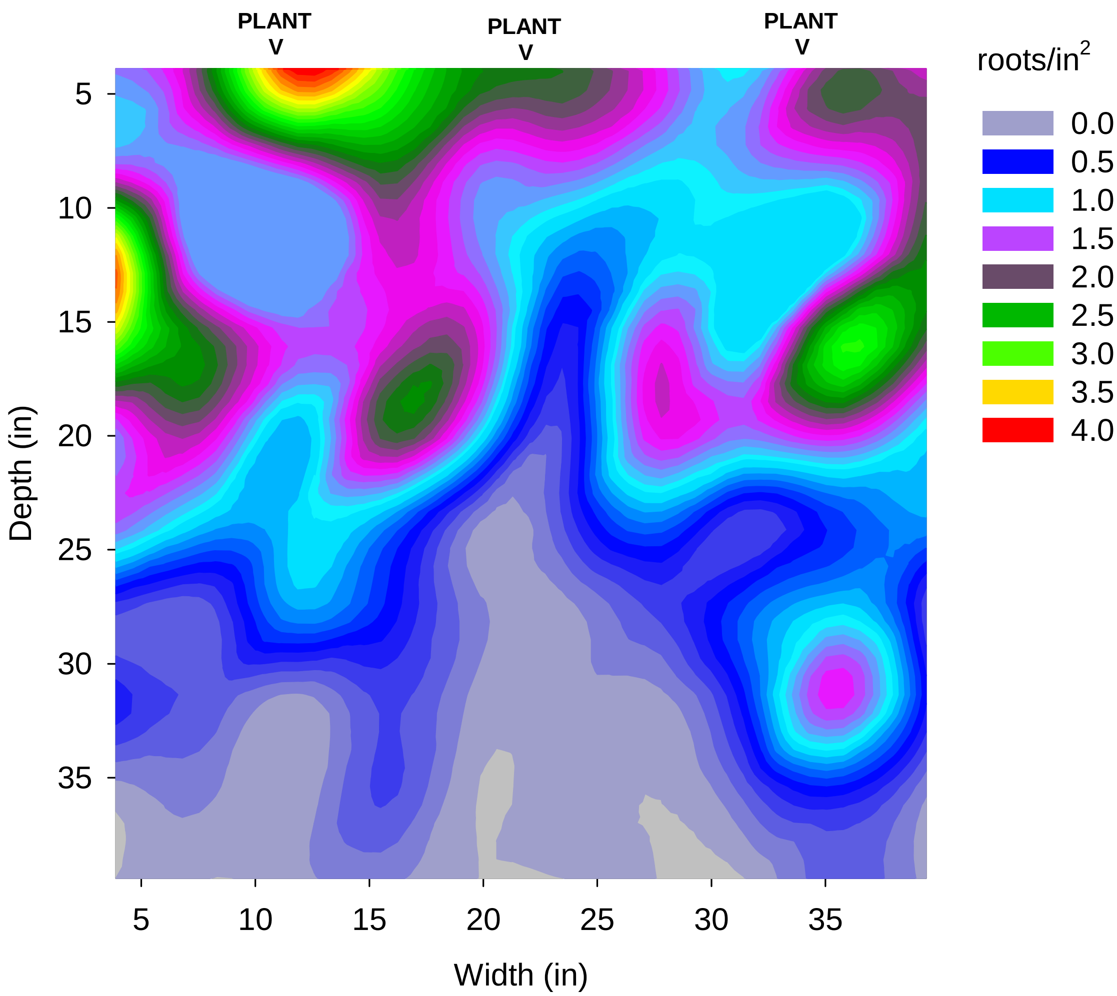

Figure 12. Cross-sectional distribution of roots of cabbage, commercially grown on 80-inch wide beds. Arrows indicate location of plant rows.

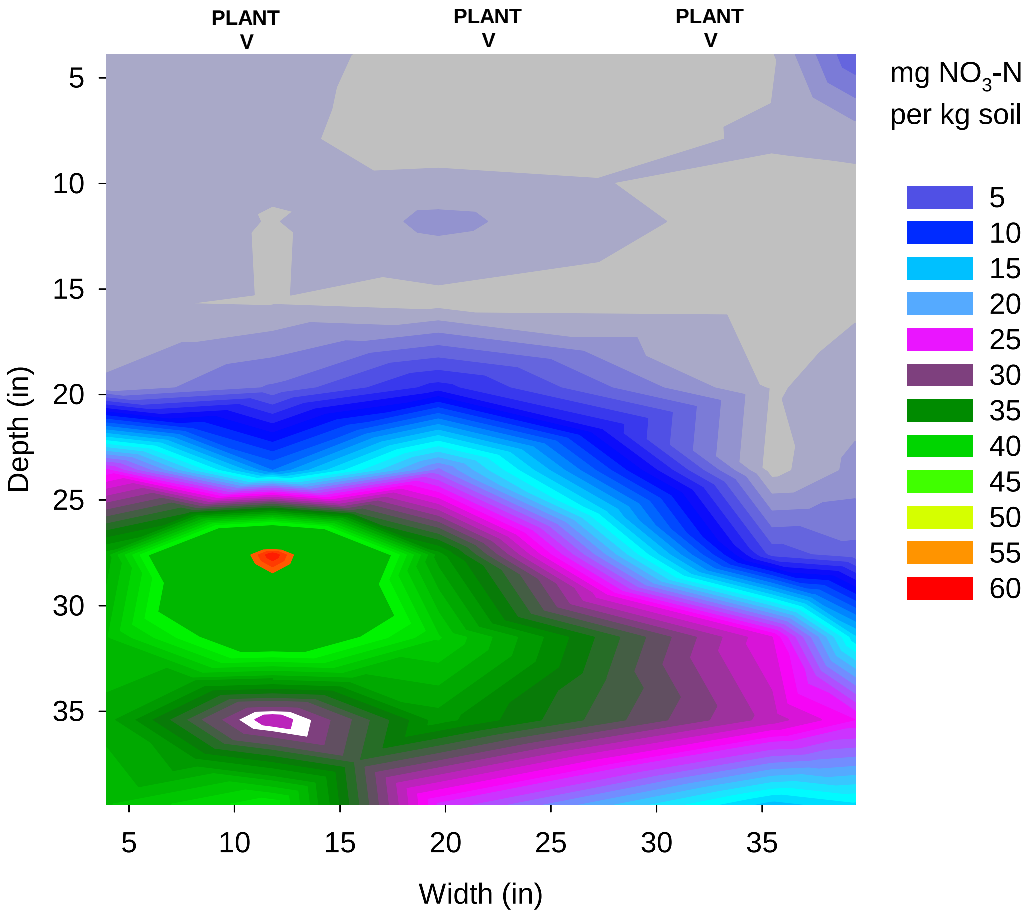

Figure 13. Cross-sectional distribution of soil NO_3-N of cabbage, grown commercially on 80-inch wide beds. Arrows indicate location of plant rows.

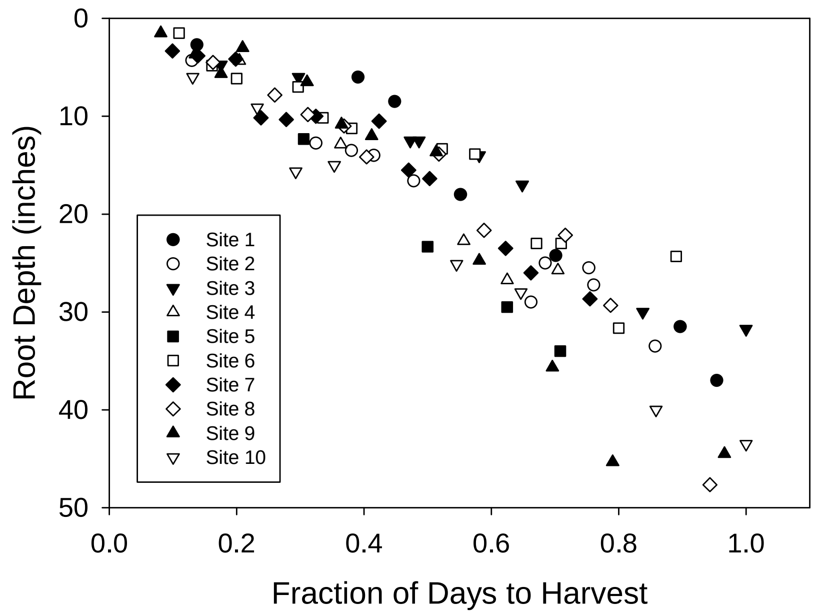

Figure 14. Rooting depth of broccoli measured in commercial fields from plant establishment to harvest.

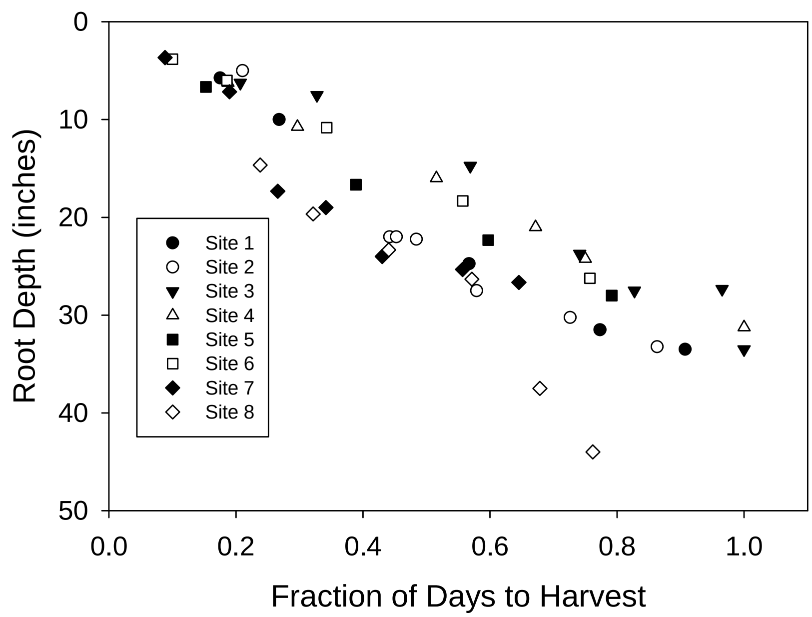

Figure 15. Rooting depth of cabbage measured in commercial fields from plant establishment to harvest.

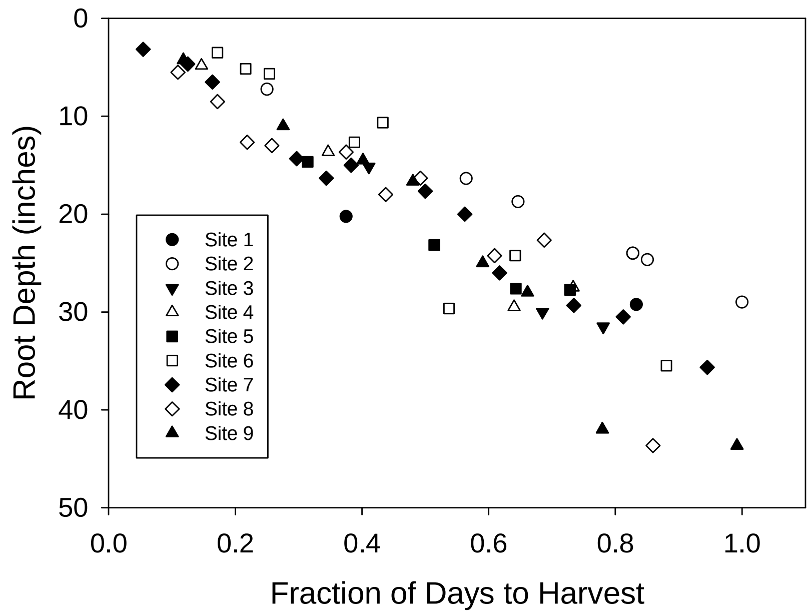

Figure 16. Rooting depth of cauliflower measured in commercial fields from plant establishment to harvest.

G. Discussion and Conclusion

The original objective of this study was to evaluate the uptake of N, water use and rooting depth of broccoli, cauliflower and cabbage. However, the results of this project showed that summer grown cole crops, and in particular broccoli, are taking up significantly greater quantities of N than are applied as fertilizer. The question that came up was, “where do these crops obtain the large quantity of N contained in the above-ground biomass?” Evaluations of the quantity of N available down to two feet deep in the soil in broccoli fields grown after lettuce indicated that there may be quantities of N in the second foot of soil that may partially provide for the needs of cole crops (this question is being more fully explored in FREP Project 13-0268-SA). We measure rooting of cole crops down 36 to 48 inches deep which may provide further evidence how cole crops meet their N needs by accessing N deeper in the soil profile. In this sense, the cole crops are retrieving N from the soil that is beyond the reach of crops such as lettuce and spinach and bring it back to the soil surface, thereby making it available for subsequent crops to access once crop residues decompose. These observations were unexpected but provide important information on the N scavenging role of cole crops in cool season vegetable rotations and are helping us to think of how we can best use cole crops to help mitigate nitrate leaching. Of course, we have to keep in mind that residues from cole crops return large quantities of N to the soil that can quickly mineralize, but this N can be accounted for and can provide for the N needs of subsequent vegetable crops by using the nitrate quick test as a guide.

Applied water data indicated that Cole crops received more water than estimated crop ET (214% to 280% of crop ET), which would have likely resulted in significant drainage below the root zone during the season. Some of the extra water was presumably needed for crop establishment and to prevent salt build up at the soil surface. Despite applying significantly more water than crop ET, soil moisture tension often reaches high values (> 60 cbars), even at the 24-inch depth. The data were consistent with a pattern of over-applying water during each irrigation event followed by a long interval between irrigations which allowed the crop to extract a significant portion of the stored soil moisture. Estimates of nitrate leaching losses, due to over-applying water, ranged from 133 to 154 lbs N/acre, assuming that the average soil nitrate concentration was 15 ppm NO_3-N and that the soil was a silt loam texture (Table 11). These results would indicate that improved water management could help improve the N use efficiency of Cole crops.

These data are helping us better understand ways to improve N recommendations for broccoli to improve utilization of the N deeper in the soil profile; algorithms have been developed to utilize this information in the CropManage Program.

H. Project Impacts

This project has been important to help us understand the role that cole crops, and in particular broccoli, plays in N cycling in the cool-season vegetable rotations along the coast. Summer-grown cole crops routinely take up more nitrogen than is applied to them as fertilizer and they can serve to retrieve N that has been leached to deeper in the soil profile and that is out of reach to crops such as lettuce and spinach. They bring this N back to the soil surface thereby providing another opportunity for this N to be utilized by crops grown after the cole crop is incorporated into the soil. In this sense, if properly managed, cole crops production can serve as a best management practice, similar to a cover crop, in the cool-season vegetable production system.

I. Outreach Activities Summary

The educational activities for this project have spanned from the Oxnard Plain and the Santa Maria Valley up to Watsonville and Salinas. Grower have had opportunities to hear about this project and many are trying to figure out ways that they can better utilize this information in their fertilization practices of cole crops. The CropManage site now has a place to include information on the nitrate levels of the second foot in the soil in order to provide more complete information on how much N is available for plant growth.

Date	Meeting	Location	Topic	Speaker	Attendance
8/21/13	CAPCA Nutrient Management Meeting	Salinas	Nutrient management update for vegetables	Richard Smith	90
9/17/13	Annual Santa Maria Vegetable Meeting	Santa Maria	Update on nutrient management studies for cool season vegetables	Richard Smith	35
10/3/13	Taylor Farms/Hartnell College Field Crop Supervisors Meeting	Salinas	Overview of fertilization of cool season vegetables	Richard Smith	35
7/12/13	Central Coast Regional Water Quality Control Board Tour	Watsonville	Irrigation and N management of lettuce	Michael Cahn	15
8/21/13	CCA Nutrient Management Seminar	Salinas	CropManage Computer Program	Michael Cahn	
9/17/13	Annual Santa Maria Vegetable Meeting	Santa Maria	CropManage: an online decision support tool for efficient irrigation and nitrogen management of vegetables	Michael Cahn	
1/14/14	Green Valley Farm Supply Fertility Meeting*	Gonzales	Nitrogen uptake dynamics of broccoli	Richard Smith	48
2/12/14	2014 Irrigation and Nutrient Management Meeting and Cover Crop Field Day	Salinas	Update on nitrogen uptake by cole crops	Richard Smith	106
3/6/14	Nitrogen and Irrigation Management Class for CCA's	Salinas	Fate and requirements of nitrogen in cool season vegetables	Richard Smith	101
4/8/14	Vegetable production meeting in Ventura County	Camarillo	Nitrogen management in leafy vegetable crops	Richard Smith	28
5/5/14	Agricultural Expert Panel Public Meeting	San Luis Obispo	Report on research on nitrogen use efficiency in cool season vegetables	Richard Smith	40

J. Fact Sheet/Data Base Template

1. Survey of Nitrogen Uptake and Applied Irrigation Water in Broccoli, Cauliflower and Cabbage Production in the Salinas Valley
2. 11-0558-SA
3. Richard Smith and Michael Cahn, University of California Cooperative Extension, Monterey County and Tim Hartz University of California, Davis
4. January 2012 to June 2014
5. Salinas, CA
6. Monterey, Santa Cruz and San Benito Counties
7. Highlights:
    - Broccoli is an important rotational crop with lettuce in the coastal production districts
    - Summer-grown broccoli and other cole crops such as cauliflower and cabbage routinely take up more nitrogen than is applied as fertilizer and may scavenge nitrate from deeper in the soil and bring it back to the soil surface where it is accessible for subsequent crops
    - CropManage, the web-based program that provides decision support to

growers for irrigation and nitrogen management, provides an option to input the levels of nitrate in the top two feet of soil to better understand the background levels of nitrogen available to broccoli when making nitrogen application decisions

8. Introduction

This project was undertaken to determine the nitrogen uptake and water use by broccoli, cauliflower and cabbage. This project was originally designed to evaluate the uptake of N, water use and rooting depth of broccoli, cauliflower and cabbage. However, we observed that broccoli and, to a lesser extent, cauliflower and cabbage take up greater quantities of N than are applied as fertilizer. Evaluations of the quantity of N available down to two feet deep in the soil in broccoli fields grown after lettuce indicated that there may be quantities of N in the second foot of soil that may partially provide for the needs of cole crops. We measured cole crop roots down to 36 to 48 inches deep which may indicate that they are accessing nitrate deeper in the soil profile than crops such as lettuce or spinach. In this sense, cole crops are retrieving N from the soil and bring it back to the soil surface, thereby making it available for subsequent crops to access once crop residues decompose. These observations are helping us to think of how we can use cole crops as a best management practice (BMP) to help mitigate nitrate leaching in intensively managed cool season vegetable rotations. As a result of this project, we have included an option in the CropManage web-based decision support program for nitrate levels in the second foot of soil to help better manage N applications to broccoli

9. Methods/Management

Thirty-eight evaluations were completed from 2012 to 2014; four evaluations of broccoli and cauliflower during the winter of 2012-13, and all other evaluations were conducted during the summers of 2012 to 2014. Crop biomass, biomass N and soil nitrate-N were measured three to four times during the growing season to measure the N uptake pattern and total N uptake. Biomass samples were collected by collecting a quantity of plants or plants from a strip of bed at random from four parts of the field in at each evaluation; the number of plants surveyed depended on the size of the plants. At harvest, total biomass and commercially harvested biomass and biomass N were measured. Also, at harvest, total crop biomass was also analyzed for phosphorus and potassium. Fertilizer application rates and timing in each field were also recorded.

Rooting depth of the crops was measured at weekly intervals during plant establishment and then bimonthly intervals until harvest. We dug down to 1 to 3 feet of depth at 3 locations in one field of each commodity each year to identify the depth of deepest roots. Pits were dug near harvest in one field of each commodity per year to expose a cross-section of the bed and map out the final root distribution. Rooting depth evaluations were initiated in the spring of 2012 and completed in June 2014.

Flow meters were installed at each monitored field to quantify the volume of water applied from crop establishment to harvest. The flow meters were connected to data loggers to record the length and frequency of irrigations. Infra-red canopy photos were taken every 2 weeks to develop crop coefficients for estimating crop ET. Soil moisture sensors were installed to monitor changes in soil moisture storage. This data provided an estimate the volume of drainage below the root zone.

10. Findings

Broccoli, cabbage and cauliflower took up about 337.4, 284.4 and 354.6 lbs N/A, respectively in the above ground biomass (Table 1). Cabbage had the highest N content in the harvested portion of the biomass at 180.3 lb N/A; 99.3 and 66.6 lbs N/A were removed in the harvested biomass of broccoli and cauliflower, respectively. Applied fertilizer averaged 181.9, 220.8 and 249.8 lbs N/A for broccoli, cauliflower and cabbage, respectively. Subtracting the quantity of N applied to the crops from the amount taken up indicated that each of these crops scavenged N from the soil. In these surveyed fields, the amount of N scavenged by broccoli, cauliflower and cabbage was 155.5, 63.6 and 104.8 lbs N/A, respectively.

Cabbage produced the highest overall biomass per acre (11,976.2 lbs/A) followed by broccoli (8,585.8 lbs N/A) then cauliflower (6,865.6 lbs N/A) (Table 2). The high percent of N in the tissue coupled with the high biomass production by these crops creates the high N uptake. The concentration of N in the overall biomass at harvest for broccoli, cauliflower and cabbage at harvest was 4.0, 4.1 and 3.0 %N, respectively. Potassium (K) concentrations in the plant tissue was equal to or higher than N in all three crops, and the concentration of phosphorus (P) ranged from 0.37 to 0.65%.

Given the disparity in the amount of N applied to broccoli vs the amount taken up we decided to sample the soil down to two feet to see if we could better understand the source of the additional N. On average, at the 1-2-foot depth, there was a substantial quantity of N at the beginning of the crop cycle through midgrowth (Table 3). These evaluations may help explain why broccoli takes up more N than is routinely applied.

K. Copy of the Product/Result

The algorithms developed by this project for crop growth, nitrogen uptake and water use are now in the CropManage web-based decision support program and are now available for growers to use to effectively fertilizer and irrigate cole crops.

UC ANR 8000 series publications will now be developed to provide technical information to assist growers to fertilizer and irrigate cole crops efficiently.

The impacts of cole crops on serving as a mean of scavenging nitrogen from deeper in the soil profile are now better understood and this information is now beginning to be used by growers and it should serve to help improve the quality of water that leaves growers fields.