A. Project Information:

Report type: Research and Demonstration

FREP grant number: 20-0960-000-SA

Time covered by the grant period: 1/1/2021 through 12/31/2023

Project title: Enhancing Nitrogen and Water Use Efficiency in California Carrot Production Through Management Tools and Practices

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B. Abstract

Extensive field measurements were conducted at the UC Desert Research and Extension Center (DREC) and 20 commercial fields in Imperial and Kern Counties to comprehensively represent various N and water management practices, soil types, climate, and carrot cultivars in California carrot production systems. At the DREC trial, three N fertilizer strategies were assessed under two irrigation regimes. In each plot, irrigation regime (as main driver) and N strategy (as secondary driver) were investigated in a Randomized Complete Block Design with Split Plot Arrangement over four replications. In the commercial trials (14 trials in Imperial County and six trials in Kern County), due to logistical limitations, the experiments were carried out in plots under irrigation and N fertilizer management practices followed by growers. Soil nitrate content (NO_3-N) and total N percentage in tops and roots were determined monthly through laboratory analysis. Plant measurements were carried out on 40-plant samples collected randomly (per plot at the DREC trial, and from five sub-areas in the commercial sites) and determinations were made on root yield and biomass accumulation, and N content. Fresh weight and dry weight of roots and foliage were measured on a regular basis. The N uptake curves suggested that nearly 50% of the total N was taken up during a 50-day period (80-130 days after seeding). This 50-day period appears to be the most critical period for N uptake, particularly in the storage roots, when carrots developed the large canopy and the extensive rooting system. The nitrogen application rates had no significant effect on total N uptake (roots and tops) and the N accumulated in roots. The N application rate had a clear and significant effect on increasing aboveground foliage (tops), which could be a reason for greater nitrogen uptake at the higher rate of N applied. The findings suggested there was an insignificant difference of fresh root yields impacted by the interaction of irrigation regime and N strategy within the range of N applications. The findings also suggested that N application rates greater than 145 lbs. ac^{-1} do not have a significant impact on carrot root yield in a well-managed irrigated field in the desert region. Higher N rates are likely necessary in over irrigated carrot fields or fields with a low residual nitrate content and fine sand soils.

C. Introduction

Carrot is a deep-rooting crop, able to efficiently extract N from soil to a depth of several feet (Westerveld 2005). Rooting depth development studies demonstrated that the rooting depth of carrot could exceed 40” at harvest (Thorup-Kristensen, 2006; Westerveld et al., 2006 a&b). Seasonal N application varies widely among growers and fields in different crop production regions. Nunez et al. (2008) reported that seasonal N rates greater than 150 lbs. N/ac are seldom necessary to maximize root yield and that excessive N application increases root cracking during harvest and handling. The period of rapid N uptake coincides with the time of rapid biomass accumulation. When N supply is adequate, crop N uptake during vegetative growth is mainly determined by crop growth rate and is therefore affected by nutrient availability and environmental conditions, such as water availability, temperature, and solar radiation. The N concentration in plant tissue, such as leaves and petioles, strongly depends on N availability.

Some carrot researchers believe that no N fertilizer should be applied within 40 days of harvest due to the danger of root splitting. Solid set sprinkler systems allow metering out the crop's N fertilizer as needed, in several small doses through the sprinklers. Fresh manure should not be applied before planting carrots. Research has shown that using fresh manure can result in forked roots. Since carrots are often grown on sandy soils, tissue analysis has been used to monitor the fertilizer status (McGiffen et al. 1997). Studies by Pettipas et al. (2006) looked at the relationship between tissue N and soil tests to determine if leaf tissue testing may be an appropriate method to monitor and meet carrot N requirements. This study showed that there were no significant differences in growth and yield of carrots in response to N regimes. Interestingly, an N rate of 0 lbs. ac^{-1} had significantly more fancy grade carrots than an N rate of 181.81 lbs. ac^{-1}, probably due to residual N. There were no significant differences in culls due to increasing N application. This study concluded that critical thresholds for leaf tissue testing were not useful for carrot N management. Overall, results showed no significant differences in soil and tissue N levels due to increasing N regimes.

Carrot roots are vulnerable to forking if too much N is applied pre-plant. If too much N is applied for the entire cropping season, the producer may see a decrease in yield (Jackson, 1979). Nitrogen deficiency in carrots is not readily apparent when viewing a field. Deficient fields might show an irregular pattern in height of the top growth, but the foliage will still be green in color.

Different deformities of a carrot root, root splitting and root rot, mostly inducing a lower proportion of marketable root, are due to excess moisture in the soil as well as to a sudden increase in soil moisture following soil moisture deficiency, suggesting the permanent need for a moderately moist soil. Nitrogen fertilization marginally increased ET due to increases in leaf area but markedly increased the water use efficiency (WUE) up to an application rate of 107 lbs. N/acre (Abdel-Mawly 2004). Gutezeit (2002) found that the highest total root yield was reached in sandy and loamy soils at 75% of available water at field capacity and 135 lbs. N/ac.

California fresh market and processing carrots comprise an area of 60,300 acres with a total value of nearly $685 million per year (California Agricultural Statistics Review 2020-2021, CDFA, data associated with crop season 2020). One of the biggest needs of the carrot industry from scientific community is looking at N uptake/removal rates and developing nitrogen uptake curves for different soil types and different carrot crops. The industry is being held responsible for determining what the most efficient nitrogen fertilization rate is, and there is high value in maintaining regulatory compliance (Irrigated Lands Regulatory Program). Most of these studies were conducted under conditions (e.g., climate, cropping system) that differ from those found in California carrot production systems. Currently, the lack of sufficient information on efficient water and N management practices is one of the largest uncertainties faced by carrot growers, hindering efficient resource-use and possibly compromising the economic sustainability of production in the face of increasingly limited and costly water and fertilizer supplies. Therefore, information on irrigation and N uptake specific to California conditions are urgently needed.

D. Objectives

The overall purpose of this project is to provide leadership to fully understand the viability and applicability of current nitrogen and irrigation management practices in California carrot production. The project aims to develop knowledge and information on improving and promoting adaptation of management practices that optimize nitrogen and irrigation water use efficiency in California carrot production systems. The long-term goal of the project is to empower the industry in making informed decisions on carrot nitrogen and water management with a resource-efficient perspective. Specific objectives are to:

- Provide data and information on crop water use and nitrogen uptake in California carrot production.
- Develop knowledge base information and data to adapt the CropManage web-based tool for water and nitrogen management of carrots.
- Disseminate the project outcomes by developing an effective outreach program.

E. Methods

A three-year study was conducted at the UC Desert Research and Extension Center and 20 commercial fields in Imperial (14 sites) and Kern (6 sites) Counties. At the DREC, the experiment consisted of three N fertilizer strategies under two irrigation regimes. The trials were arranged in a randomized complete block with split plot arrangement over four replications. Each sub-plot included 12 beds of 40-in. width and 60 ft. long (40 ft × 60 ft). Ten lines of Choctaw fresh market cultivar were seeded in each bed. Solid-set sprinkler was used to irrigate the trials throughout the growing seasons.

Due to logistical limitations in the commercial sites, in each of the trial fields an assigned plot with an area of 300 feet by 300 feet was selected and all the measurements were conducted within the assigned plots. Within the experimental assigned area of each field, five sub-areas (each will have an area of 50 feet by 50 feet) were determined for soil-plant samplings and monitoring the entire crop season. The fertilizer applied were monitored throughout the crop season.

Actual soil nitrate content (NO_3-N) and total N percentage in tops and roots were determined monthly through laboratory analysis. Preplant and post-harvest soil samples were taken from six depths (1-6 ft.). At other sampling dates, soil was collected from the top three depths (1-3 ft.). A composite soil sample was analyzed from each layer for NO_3-N content. In addition, a soil quick N test was conducted from the top 12" of the soil in each trial field on a 10-day basis.

The actual consumptive water use (actual crop ET; ET stands for crop evapotranspiration) was measured using the residual of the energy balance method with a combination of surface renewal and eddy covariance equipment. As an affordable tool to estimate actual crop ET, Tule Technology sensors were also set up at all experimental sites. The Tule ET data were verified using the ET estimates from the fully automated ET tower. Canopy images were taken on a weekly to a 15-day basis utilizing an infrared camera (NDVI digital camera) to quantify crop canopy coverage over the crop seasons. Plant measurement was carried out on 40-plant samples collected randomly per replication of each treatment/sub-areas, and determinations of fresh and dry weights of roots and foliage were made on a regular monthly basis during the seasons. The plant measurement was conducted on 100-plant samples per plot at harvest.

F. Data/Results

Irrigation management

The common irrigation practice in carrot stand establishment in the low desert is to irrigate the field every other day using sprinkler systems during the first two weeks after seeding. Carrots germinate slowly, and hence, the beds need to be kept moist to prevent crusting. A comparison between the averages of applied water and actual consumptive water use for a 30-day period after seeding suggested that carrots are typically over-irrigated during plant establishment. An average of 3.8 in was measured as actual consumptive water use for this period across the experimental sites (Fig. 3), while the applied water varied from two to three times this amount.

The results clearly demonstrated that the carrot sites had variable actual consumptive water uses depending upon early/late planting, irrigation practice, length of crop season, soil type, and weather conditions. For instance, site C-4 (Fig. 3) was a sprinkler irrigated field with a dominant soil texture of sandy clay loam where the carrots were harvested very late, 193-day after seeding. The seasonal consumptive water use was 19.2 in at this site. The results show that the seasonal crop water use of fresh market carrots is nearly 16.0 in for a typical crop season of 160-day with planting in October. Approximately 50% of crop water needs occurred during the first 100 days after seeding and the other 50% during the last 60 days before harvest. A crop canopy model developed in this study demonstrated that fresh market carrots reach 85% canopy coverage by 100 DAS (day after seeding) (Fig. 4).

Water stress should be avoided throughout the carrot growing cycle. The critical period for irrigation is between fruit set and harvest. Sprinkler irrigation may be considered as a more effective irrigation tool when compared with furrow irrigation. More frequent and light irrigation events are possible by sprinkler irrigation. Over-irrigation of carrot fields increases the incidence of hairy roots; and severe drying and wetting cycles result in significant splitting of roots. Sprinklers also reduce salinity issues which is important since carrots are very sensitive to salt accumulation.

Nitrogen management

The results demonstrated that a wide range of N accumulated both in roots and tops at harvest (Fig. 5). For instance, a total N content of 312.9 lbs. ac^{-1} was observed in a fresh market carrot field with a long growing season of 193-day, including 202.9 and 110.0 lbs. N/ac in roots and tops, respectively. The total N accumulated in plants (roots + tops) was less than 265 lbs. ac^{-1} in the other sites.

A linear regression model was found for the total N uptake in roots after 60-73 DAS without declining near harvest (Fig. 5). Small gradual increases in N contents of roots were observed until about 65 DAS. This suggested that N begins to accumulate at a rapid rate between 65 and 80 DAS; however, the period of rapid increase could vary depending on early (September) or late (November) plantings. N uptake in tops increased gradually following a quadratic regression, and in most sites levelled off or declined slightly late in the season. Although the N accumulated in tops appeared to drop down or level off in most sites beyond 120 to 145 DAS, the N content decline occurred after DAS 155 at site C-4 with a longer growing season.

These findings suggest that a total N accumulation of 260 lbs. ac^{-1} occurred by 160 DAS, with 145 lbs. ac^{-1} in roots and 115 lbs. ac^{-1} in tops. Across all sites, nearly 28% of seasonal N accumulation occurred by 80 DAS (Fig. 6), when the canopy cover reached an average of 67% (Fig. 4). The large proportion of this N content was taken up during a 30-day period (50 DAS – 80 DAS). The results also suggest that nearly 50% of the total N was taken up during a 50-day period (80 DAS through 130 DAS). This 50-day period appears to be the most critical period for N uptake, particularly in the storage roots, when carrots developed the large canopy and the extensive rooting system. The majority of N is taken up during the months of December to February, and hence, proper N fertility in the effective crop root zone is essential during this period. For a 160-day crop season, 22% of N uptake could be accomplished over the last 30-day before harvest.

Carrots have a deep rooting system that allows for improved capture of N from deep in the soil profile. There is a risk of leaching soil residual N due to heavy pre-irrigation (a common practice for salinity management in the low desert) in late summer prior to land preparation. N is likely accumulated at the deeper depths by the beginning of the growing season, and consequently, there is a potential N contribution from the soil for carrots when the roots are fully developed. Since residual soil N contribution can be considerable in carrots, preplant soil nitrate-N assessment down to 60-cm depth could be a tool enabling farmers to improve N management and maximize yield and quality while minimizing economic and environmental costs.

Water and nitrogen applied at the DREC Trials

The seasonal water and N applications in the different irrigation regimes and N strategies for the two seasons of 21-22 and 22-23 are given in Table 1. A preplant N fertilizer with monoammonium phosphate was broadcasted at a rate of 280 lbs./ac over the entire trial area in both seasons. Urea Ammonium Nitrate (UAN-32) was injected into the sprinkler system to supply the remainder amount of the N for each nitrogen treatment. The application rates varied from 140 to 235 lbs. N/ac in the 21-22 season and from 145 to 217 lbs. N/ac in the 22-23 season.

The amount of irrigation water was determined using the CropManage irrigation and nitrogen decision management tool (https://cropmanage.ucanr.edu) to provide 100% of crop water needs (ET or irrigation regime 1) and 25% more than crop water needs (125% ET or irrigation regime 2). The amounts of irrigation varied from 24.5 to 30.8 in. and from 23.6 to 29.7 in. in the season 21-22 and 22-23, respectively (Table 1).

Impact of water and N management on nitrogen uptake (DREC's Trials)

The highest N accumulation rates at harvest were associated with the N2 treatment under the I2 irrigation regime (273 lbs. ac^{-1}) and the N3 treatment under the I1 irrigation regime (281 lbs. ac^{-1}) in the 22-23 season (Fig. 6). However, nitrogen application rates had no statistically significant effect on total N uptake (roots and tops) and the N accumulated in roots. The N application rate had a clear and scientifically significant effect on increasing aboveground foliage (tops) in which could be a reason for greater nitrogen uptake at the higher rate of N applied.

The results provide evidence (p=0.01) for an overall effect of the interaction of irrigation regime and nitrogen management strategy on the total N accumulation in carrots (roots and tops) even though the irrigation regime as an individual driver had no significant effect on the N accumulation (neither the total nor tops or roots). It is likely relevant to the range of water application rates. The 25% over irrigation couldn't have a considerable impact on leaching nitrate within a silty loam soil type. A higher amount of excessive water through a more aggressive over irrigation scenario (for instance 150% ET) could influence the N uptake differently. The results of nitrogen accumulation were basically consistent within the two seasons.

Impact of water and N management on carrot fresh roots (DREC's trials)

Although no statistically significant impacts were found from both irrigation and N application rates on the fresh root yield (p values of greater than 0.41) in the 22-23 season, N application statistically affected root yield (p=0.001) in the 21-22 season (Fig.

6). The lowest fresh root yield (40.8 t ac^{-1}) was observed in the I2N1 treatment (irrigation regime 2 and an N application rate of 140 lbs. ac^{-1}). A lower soil residual nitrate content could have contributed to a lower root yield in this specific treatment in the 21-22 season. A greater mineral N content in the top 2-ft of soil was determined right before planting in the 22-23 season (106 lbs. N/ac) than in the 21-22 season (77 lbs. N/ac).

Since residual soil N can contribute considerably to the N requirement in carrots, preplant soil nitrate-N assessment down to 2 ft. depth is a tool that can enable growers to improve N management and maximize yield and quality while minimizing economic and environmental costs.

The findings suggested there was an insignificant difference of fresh root yields impacted by the interaction of irrigation regime and N strategy within the range of application rates in both seasons. Different results could be obtained in a field that is irrigated more than the I2 treatment (> 125% of CropManage recommendation), has a low residual nitrate content or/and has a sandy textured soil.

G. Discussion and Conclusions

Careful management of N applications in the low desert carrots is crucial because fertilizers are the main source of N, particularly due to low organic matter content of the soils and very low nitrate level of the Colorado River water. Knowing this fact, the soil NO_3-N contents pre-seeding and over the growing season at different sites revealed that none of the sites had N deficiency during the crop season, and consequently, the practice of splitting N applications, as done by the farmers (applying 9-15% of total seasonal N as preplant, and the remainders through irrigation events over the season), was likely effective in most cases. It appears that the practice of 15-30% seasonal N application though irrigation events 45-70 days after seeding has as similar effectiveness of sidedress N application.

In the low desert of California, the majority of N is taken up during the months of December to February, and hence, proper N fertility in the effective crop root zone is essential during this period. An integrated optimal N and water management plan needs to be followed to achieve high N and water efficiency, and consequently overall profitability.

Within the range of N application rates examined at the experimental sites, there were no significant relationships between carrot fresh root yield and N application rate, although the results suggested a positive effect of N application on carrot yield (Table 2). Sufficient N availability in the crop root zone over the growing season and the lack of significant yield response to N application demonstrate that N optimal rates could be likely less than the applied amounts in most sites. Adequate nitrogen and water applications reduce costs and help prevent leaching, while excess N may lead to excessive N storage in the roots, which may be a concern for processing carrots. An integrated optimal N and water management needs to be approached to accomplish greater N and water use efficiency, and consequently keeps lower rates that are beneficial to overall profitability.

Carrots need variable seasonal water application that depends on planting time, length of season, variety, soil types, and irrigation efficiency. In this study, we used CIMIS reference evapotranspiration data and a crop coefficient model applied through CropManage online software to estimate water requirements of carrot before each irrigation.

It is important to note that due to overirrigating carrots, positive impacts could be observed from higher N rates in some cases, particularly in sandy soils with a high leaching potential. In other words, an integrated optimal N and water management needs to be approached to accomplish greater N and water efficiency, and consequently keeping lower rates beneficial to overall profitability. Sufficient N availability in the crop root zone over the growing season and the lack of significant yield response to N application within the range of N application rates in this study suggested that N optimal rates could be likely less than 180 lbs. ac^{-1} in the low desert of California. N removal at harvest varied from 2.3 to 3.9 lbs. t^{-1} with an average of 3.0 lbs.t^{-1} of fresh carrot root.

Growers are encouraged to try using a reduced N rate (10-20% lower than their current practice) on a small field to evaluate how it fits their specific farming practices before they adopt it on a widespread basis. Analyzing soil samples for residual soil nitrate early in the season (after the pre-irrigation) and in-season soil nitrate and leaf tissue analyses can provide confidence in the new practices and allow for corrective measures.

H. Challenges

None

I. Project Impacts

- N uptake curve and N crop removal coefficient were developed for desert carrots. These tools assist growers and researchers to better understand carrot nitrogen requirements over the season and manage N fertilizer application rates accordingly.
- CropManage irrigation and N management tool was adopted for carrots. CropManage carrot module was developed and evaluated for carrot fields in the low desert region. This user-friendly web-based tool assists carrot growers on irrigation and nitrogen best management practices.
- Recommendations were developed on crop water use and nitrogen best management practices in California carrot production systems.
- The tools and information developed by the study were disseminated to growers and stakeholders in California. Several growers have already adopted these tools and information for carrot irrigation and fertilizer management.

J. Outreach Activities Summary

Event Name (1)	UCCE Imperial Vegetable Crops and IPM Workshop		
Presentation title	Irrigation and nitrogen best management practices in the low desert carrots		
Location and date	Virtual - Feb 25, 2021		
Attendee demographics (CCAs, PCAs, growers, consultants, researchers, etc.)	CCAs, PCAs, growers, consultants, researchers, and student		
CCA/Grower Continuing Education Units (CEUs) offered	CALIFORNIA DPR (1.5 hrs.), ARIZONA DEPT. Of AG (1 hrs.) & CCA (2.5 hrs.)	**Number of participants**	45

Event Name (2)	Annual Carrot Research Symposium		
Presentation title	Irrigation and nitrogen best management practices in the low desert carrot production system		
Location and date	Virtual - March 22, 2021		
Attendee demographics	CCAs, PCAs, growers, consultants, researchers, and student		
CCA/Grower Continuing Education Units (CEUs) offered	California DPR (2.0 hrs.)	**Number of participants**	75

Event Name (3)	Presentation in the Imperial Valley Vegetable Growers Association's meeting		
Presentation title	New Information Developed on Water-Nitrogen Best Management Practices in Desert Carrots		
Location and date	December 13, 2021		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	38

Event Name (4)	Presentation in the Imperial County Farm Bureau's meeting		
Presentation title	Carrot study and what we've learned so far		
Location and date	October 20, 2021		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	46

Event Name (5)	Extension publication		
Presentation title	Best irrigation management practices in the low desert carrots		
Location and date	Agricultural Briefs-Imperial County 23 (7): 97-100		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	-

Event Name (6)	Extension publication		
Presentation title	Article: BEST WATER AND NITROGEN MANAGEMENT PRACTICES IN THE LOW DESERT CARROTS: A PRELIMINARY ASSESSMENT		
Location and date	Agricultural Briefs-Imperial County 26 (6): 87-92 - June 2021		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	-

Event Name (7)	Trade journal article (Progressive Crop Consultant)		
Presentation title	New Knowledge-Based Information Developed to Enhance Water and Nitrogen Use Efficiency in Desert Fresh Market Carrots		
Location and date	September 7, 2021		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	-

Event Name (8)	Trade journal article (Carrot Country Magazine)		
Presentation title	Needs assessment: The latest science-based information on water and nitrogen best management practices for low desert carrots		
Location and date	Carrot Country Magazine, Summer 2021		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	-

Event Name (9)	Peer-reviewed journal article		
Presentation title	Spatial Variability of Nitrogen Uptake and Net Removal and Actual Evapotranspiration in the California Desert Carrot Production System		
Location and date	Journal of Agriculture: 11(8): 752 August 2021		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	-

Event Name (10)	Interviewed by Progressive Crop Consultant		
Presentation title	Carrot Trials Target Water and Nitrogen Efficiency		
Location and date	Progressive Crop Consultant June 14, 2021		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	-

Event Name (11)	Interviewed by News & Events - Division of Agriculture and Natural Resources		
Presentation title	New research fills gap on best practices for California carrot production		
Location and date	Sep 24, 2021(first time published) *This article was also republished by Imperial Valley Press, Progressive Crop Consultant, and Western Farm Press. Also republished in the websites of several UCCE offices.*		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	-

Event Name (12)	Interviewed by My AG Podcast Life		
Presentation title	Irrigation and Nitrogen Management in Carrot		
Location and date	December 17, 2021		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	-

Event Name (13)	Interviewed by AgNet West Radio Network		
Presentation title	Irrigation research findings on carrot production in desert conditions		
Location and date	September 30, 2021		
Attendee demographics	-		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	-

Event Name (14)	UCCE Imperial Vegetable Crops and IPM Workshop		
Presentation title	New Information Developed on Water-Nitrogen Best Management Practices in Desert Carrots		
Location and date	Virtual – March 10, 2022		
Attendee demographics (CCAs, PCAs, growers, consultants, researchers, etc.)	CCAs, PCAs, growers, consultants, researchers, and students		
CCA/Grower Continuing Education Units (CEUs) offered	CALIFORNIA DPR (1.5 hrs.), ARIZONA DEPT. Of AG (1 hrs.) & CCA (2.5 hrs.), CA FREP (1.5 hrs.	**Number of participants**	55

Event Name (15)	California Annual Carrot Research Symposium		
Presentation title	Best Irrigation and nitrogen management practices in the low desert carrot production systems		
Location and date	Virtual - March 21, 2022		
Attendee demographics (CCAs, PCAs, growers, consultants, researchers, etc.)	CCAs, PCAs, growers, consultants, researchers, and students		
CCA/Grower Continuing Education Units (CEUs) offered	California DPR (2.0 hrs.)	**Number of participants**	87
Event Name (16)	CropManage Hands-on Training Workshop in the Coachella Valley		
Presentation title	4-hour training workshop		
Location and date	City of Coachella Corporate Yard, 53-462 Enterprise Way, Coachella, CA 92236 February 9, 2022		
Attendee demographics (CCAs, PCAs, growers, consultants, researchers, etc.)	CCAs, PCAs, growers, consultants, researchers		
CCA/Grower Continuing Education Units (CEUs) offered	CCA (2.5 hrs.)	**Number of participants**	17

Event Name (17)	CropManage Hands-on Training Workshop in the Imperial Valley		
Presentation title	4-hour training workshop		
Location and date	Farm Credit West, 485 Business Parkway, Imperial, CA 92251 February 10, 2022		
Attendee demographics (CCAs, PCAs, growers, consultants, researchers, etc.)	CCAs, PCAs, growers, consultants, researchers		
CCA/Grower Continuing Education Units (CEUs) offered	CCA (2.5 hrs.)	**Number of participants**	10

Event Name (18)	Cultivating the Desert Workshop: Vegetable Production Challenges and Opportunities in Coachella Valley		
Presentation title	Best Irrigation and Nitrogen Management Practices in Desert Carrots		
Location and date	City of Coachella Corporate Yard, 53-462 Enterprise Way, Coachella, CA 92236 February 9, 2022		
Attendee demographics (CCAs, PCAs, growers, consultants, researchers, etc.)	CCAs, PCAs, growers, consultants, researchers, students		
CCA/Grower Continuing Education Units (CEUs) offered	CCA (2.5 hrs.)	**Number of participants**	45

Event Name (19)	Annual Carrot Research Symposium		
Presentation title	Irrigation and nitrogen best management practices in the low desert carrot production system		
Location and date	Virtual – Feb 14, 2023		
Attendee demographics	CCAs, PCAs, growers, consultants, researchers, and student		
CCA/Grower Continuing Education Units (CEUs) offered	California DPR (2.0 hrs.)	**Number of participants**	85

Event Name (20)	UCCE 34th Fall Desert Crops Workshop		
Presentation title	Tools and information to enhance nitrogen-water use efficiency in desert carrots		
Location and date	Farm Credit Services Southwest, Ag Center Room –Imperial November 30, 2023		
Attendee demographics (CCAs, PCAs, growers, consultants, researchers, etc.)	CCAs, PCAs, growers, consultants, researchers, and students		
CCA/Grower Continuing Education Units (CEUs) offered	CALIFORNIA DPR (2.5 hrs.), ARIZONA DEPT. Of AG (2.5 hrs.) & CCA (4 hrs.)	**Number of participants**	60

Event Name (21)	2023 CDFA Annual FREP & WPH Conference		
Presentation title	Tools and information to enhance nitrogen and water use efficiency in California carrots		
Location and date	Modesto, CA November 8-9, 2023		
Attendee demographics (CCAs, PCAs, growers, consultants, researchers, etc.)	CCAs, PCAs, growers, consultants, researchers, and students		
CCA/Grower Continuing Education Units (CEUs) offered	-	**Number of participants**	100

K. References

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L. Appendix

Fig.1. Magnetic flowmeters and data store and transfer equipment to monitor water applied to the trial (left) and monitoring station in treatment I1N1 at the UC DREC trial (right).

Fig. 2. Fully automated ET tower (right) and a multi depths soil moisture sensor monitoring station equipped along with Tule sensor in commercial sites (left).

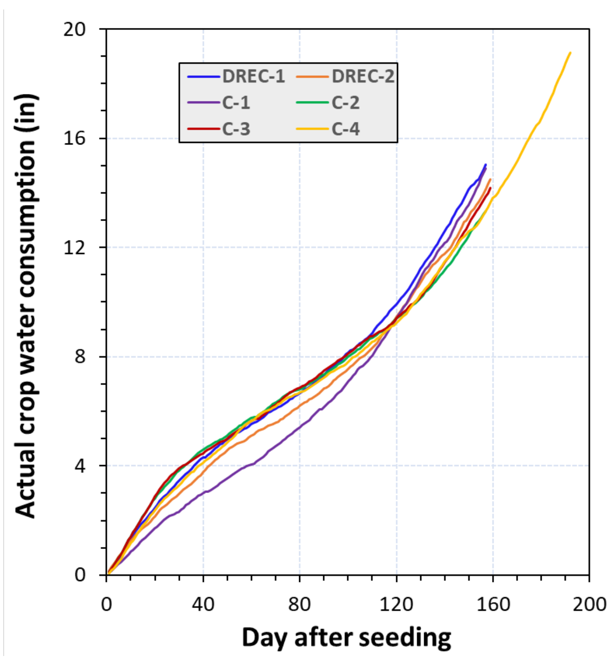

Fig. 3. Cumulative actual crop water consumption (actual ET) at each of the experimental sites (desert region). Surface renewal actual daily ET is reported here.

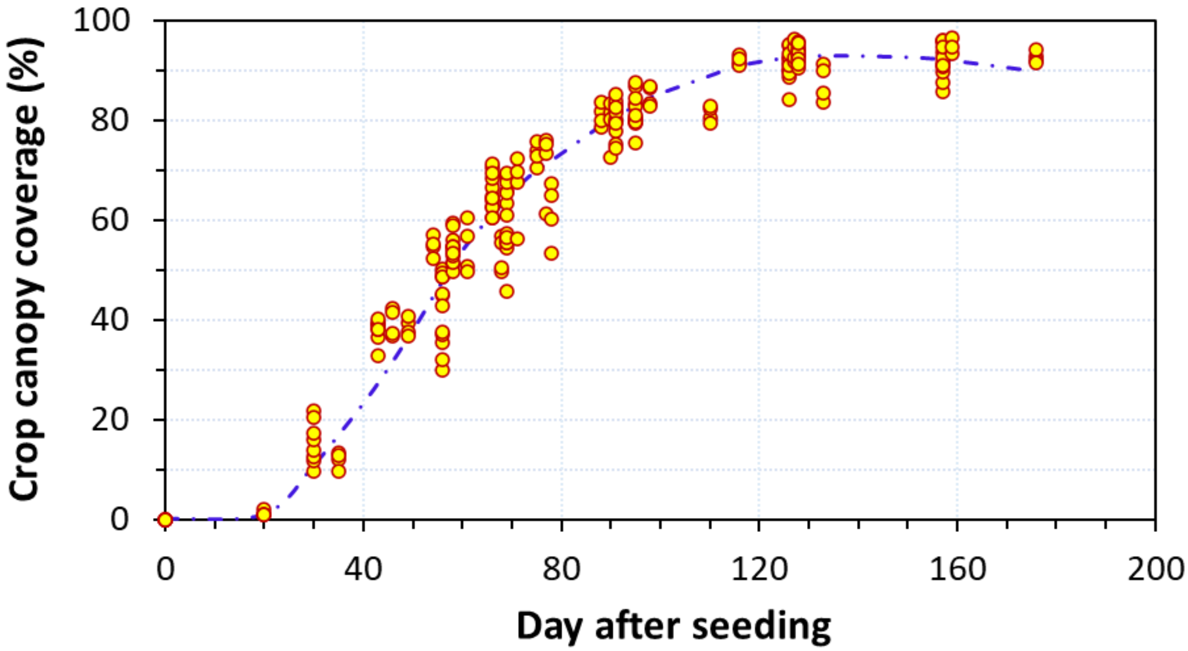

Fig. 4. Canopy development curve for the low desert fresh market carrots over the growing season.

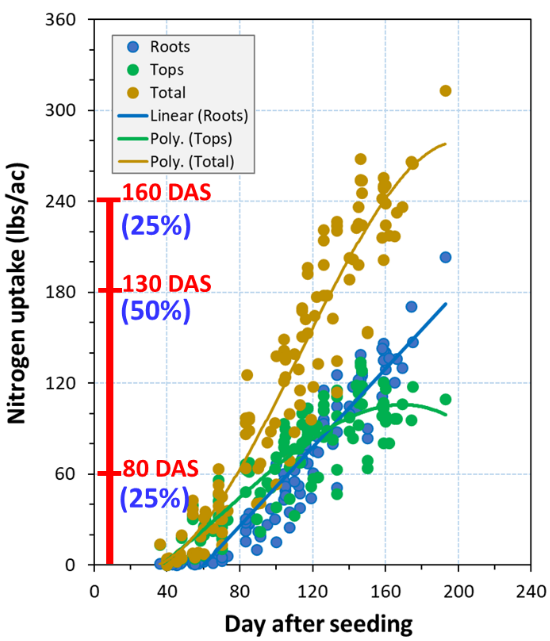

Fig. 5. N accumulation trends in storage roots, tops, and total (plants) over the growing season at the experimental sites.

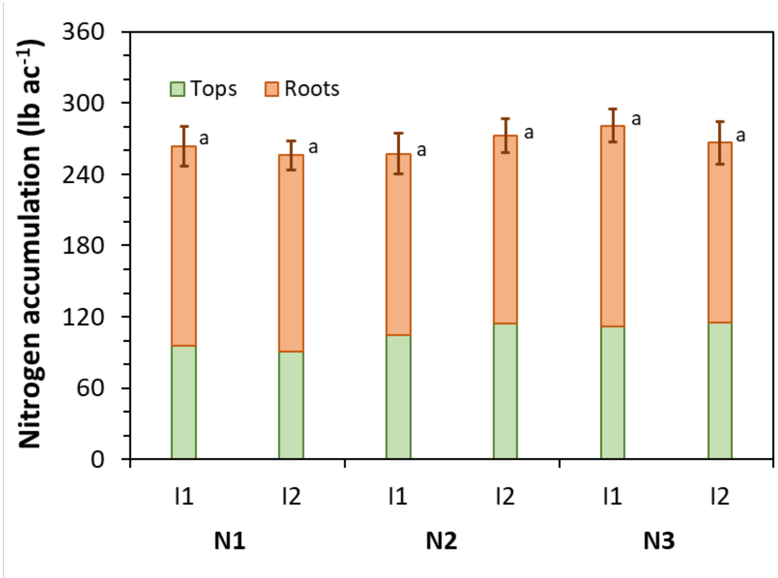

Fig. 6. Mean nitrogen uptake distribution in carrot roots and tops affected by water regimes and nitrogen application rates in the 22-23 season. The bars demonstrate the standard error of root yield values. Fresh root yields with different letters significantly differ ($p < 0.05$) by Tukey's test.

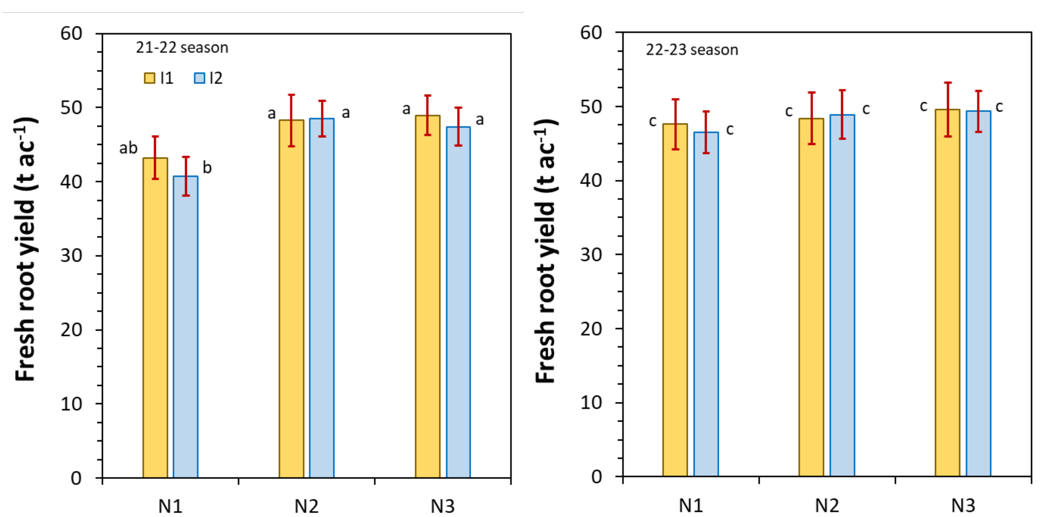

Fig. 7. Mean fresh carrot root yields as affected by water regimes and nitrogen application rates over the study seasons. The bars demonstrate the standard error of root yield values. Fresh root yields with different letters in each season significantly differ ($p < 0.05$) by Tukey's test.

Table 1. Seasonal water and N application rates in the study seasons.

	21-22 season	22-23 season
N application (lb. N/ acre)	N1=140 N2=185 N3=235	N1=145 N2=180 N3=217
Water application (in)	I1=24.5 I2=30.8	I1=23.6 I2=29.7

Table 2**.** Mean fresh storage root yields ((±standard deviation) at the experimental sites (data of the trials conducted over two crop seasons at DREC and nine commercial fields in the desert region were adopted for this analysis).

Experimental Site		N Applied (lb/ac)	Mean ± SD (t/ac)
Fresh market carrots	DREC-1 (20–21)	176.3	47.5 ± 3.7
	DREC-1 (19–20)	183.2	50.1 ± 4.8
	I	197.2	47.1 ± 4.0
	DREC-2 (20–21)	207.6	48.0 ± 3.4
	DREC-2 (19–20)	213.8	51.1 ± 4.3
	VIII	229.1	60.2 ± 5.9
	III	247.8	54.8 ± 4.6
	II	262.2	53.3 ± 3.1
	DREC-3 (20-21)	266.3	45.7 ± 4.2
	DREC-3 (19-20)	272.6	49.4 ± 4.8
	Significance	L	NS
		Q	NS
		R^2	-
Processing carrots	IV	189.1	38.0 ± 4.5
	VI	197.1	43.1 ± 3.9
	VII	221.2	46.2 ± 4.3
	IX	230.8	48.9 ± 5.1
	V	237.5	43.7 ± 4.7
	Significance	L	NS
		Q	NS
		R^2	-

^{NS} non-significant. * Significant at the 5% level of probability.
L: linear regression. Q: quadratic regression. SD: Standard deviation

M. Factsheet/Database

1. Project Title: Enhancing Nitrogen and Water Use Efficiency in California Carrot Production Through Management Tools and Practices

2. Grant Agreement Number: 20-0960-000-SA

3. Project Leaders: (1) Ali Montazar, Irrigation and Water Management Advisor, UCCE Imperial County; (2) Daniel Geisseler, Nutrient Management Specialist, Dept. of LAWR, UC Davis; (3) Michael Cahn, Irrigation and Water Resources Advisor, UCCE Monterey County; (4) Jaspreet Sidhu, Vegetable Crops Farm Advisor, UCCE Kern County

4. Start Year/End Year: 2021/2023

5. Location: UC Desert Research and Extension Center & Commercial fields in Imperial and Kern Counties

6. County: Imperial and Kern Counties

7. Highlights

- Carrots are typically over-irrigated during plant establishment.
- N uptake curve was developed for desert carrot.
- N application rates greater than 145 lbs. ac^{-1} do not have a significant impact on carrot root yield in a well-managed irrigated field.
- CropManage irrigation and N management tool was adopted for carrots.
- An average N removal of 3.0 lbs. t^{-1} of fresh carrot root was determined for desert carrots.

8. Introduction

California fresh market and processing carrots comprise an area of 60,300 acres with a total value of nearly $685 million per year. One of the biggest needs of the carrot industry from the scientific community is looking at N uptake/removal rates and developing nitrogen uptake curves for different soil types and different carrot crops. The industry is being held responsible for determining what the most efficient nitrogen fertilization rate is, and there is high value in maintaining regulatory compliance. Currently, the lack of sufficient information on efficient water and N management practices is one of the largest uncertainties faced by carrot growers, hindering efficient resource-use and possibly compromising the economic sustainability of production in the face of increasingly limited and costly water and fertilizer supplies. Most of studies conducted on irrigation and nitrogen management were under conditions (e.g., climate, cropping system) that differ from those found in California carrot production systems. Therefore, information on irrigation and N uptake specific to California conditions are urgently needed. This study is intended to develop new information on N uptake curves, net N removal, crop water use for carrot production systems and adopting CropManage web-based tool for water and N management in carrots.

9. Methods/Management

A three-year study was conducted at the UC Desert Research and Extension Center and 20 commercial fields in Imperial and Kern Counties. At the DREC, the experiment consisted of three N fertilizer strategies under two irrigation regimes. The trials were arranged in a randomized complete block with split plot arrangement over four replications. Each sub-plot included 12 beds of 40-in. width and 60 ft. long (40 ft × 60 ft). Due to logistical limitations in the commercial sites, in each of the trial fields an assigned plot with an area of 300 feet by 300 feet was selected and all the measurements were conducted within the assigned plots. Within the experimental assigned area of each field, five sub-areas (each will have an area of 50 feet by 50 feet) were determined for soil-plant samplings and monitoring the entire crop season. Actual soil nitrate content (NO_3-N) and total N percentage in tops and roots were determined monthly through laboratory analysis. The actual consumptive water use (actual crop ET) was measured using the residual of the energy balance method with a combination of surface renewal and eddy covariance equipment. Canopy images were taken on a weekly to a 15-day basis utilizing an infrared camera (NDVI digital camera) to quantify crop canopy coverage over the crop seasons. Plant measurement was carried out on 40-plant samples collected randomly per replication of each treatment/sub-areas, and determinations of fresh and dry weights of roots and foliage were made on a regular monthly basis during the seasons. The plant measurement was conducted on 100-plant samples per plot at harvest.

10. Findings

The results clearly demonstrated that the carrot sites had variable actual consumptive water uses depending upon early/late planting, irrigation practice, length of crop season, soil type, and weather conditions. In the desert region, approximately 50% of crop water needs occurred during the first 100 days after seeding and the other 50% during the last 60 days before harvest for a typical 160-day crop season.

The results demonstrated a wide range of N accumulated both in roots and tops at harvest. A linear regression model was found for the total N uptake in roots 60-73 DAS (days after seeding) without declining near harvest. Small gradual increases in N contents of roots were observed until about 65 DAS. This suggested that N begins to accumulate at a rapid rate between 65 and 80 DAS, however, the period of rapid increase could vary depending on early or late plantings. N uptake in tops increased gradually following a quadratic regression, and in most sites levelled off or declined slightly late in the season. The N accumulated in tops appeared to drop down or level off in most sites beyond 120 to 145 DAS. Nitrogen application rates had no significant effect on total N uptake and the N accumulated in roots. The N application rate had a clear and significant effect on increasing aboveground foliage (tops), which could be a reason for greater nitrogen uptake at the higher rate of N applied. The findings suggested insignificant differences in fresh root yields impacted by the interaction of irrigation regime and N strategy within the range of application rates (140 to 275 lbs. N/ac). N application rates greater than 145 lbs. ac^{-1} did not have a significant impact on carrot root yield in a well-managed irrigated field. However, higher N rates are likely necessary in over irrigated carrot fields and/or sandy soils to maximize root yield. An average N removal of 3.0 lbs.t^{-1} of fresh carrot root was determined for desert carrots.

N. Copy of the Product/Result

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Spatial Variability of Nitrogen Uptake and Net Removal and Actual Evapotranspiration in the California Desert Carrot Production System

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Abstract: Nitrogen (N) and irrigation water must be effectively used in mineral soils to produce carrots with high yield and minimal environmental impact. This study attempts to identify optimal N and irrigation management practices for low desert carrot production in California by investigating consumptive water use and N uptake and removal rates in fresh market and processing carrots. Field experiments were conducted at the University of California Desert Research and Extension Center and nine farmer fields during two growing seasons. The actual evapotranspiration (ET_a) was measured using the residual energy balance method with a combination of surface renewal and eddy covariance equipment. Crop canopy coverage, actual soil nitrate-N from multiple depths as well as total N percentage, dry matter, and fresh biomass in roots and tops were measured over the growing seasons. The length of the crop season had a wide range amongst the experimental sites: from a 128-day period in a processing carrot field to as long as 193 days in a fresh market carrot field. The seasonal ET_a varied between 305.8 mm at a silty loam furrow irrigated processing carrot field and 486.2 mm at a sandy clay loam sprinkler irrigated fresh market field. The total N accumulated at harvest ranged between 205.4 kg ha^{-1} (nearly 52% in roots) and 350.5 kg ha^{-1} (nearly 64% in roots). While the mean value of nitrogen removed by carrot roots varied from 1.24 to 1.73 kg N/Mg carrot roots, it appears that more N was applied than was removed by carrot roots at all sites. Within the range of N application rates examined at the experimental sites, there was no significant relationship between carrot fresh root yield and N application rate, although the results suggested a positive effect of N application on carrot yield. Sufficient soil N availability over the growing season and the lack of significant yield response to N application illuminated that optimal N rates are likely less than the total amounts of N applied at most sites.

Keywords: carrots; irrigation management; low desert of California; nitrate N; nitrogen uptake curve

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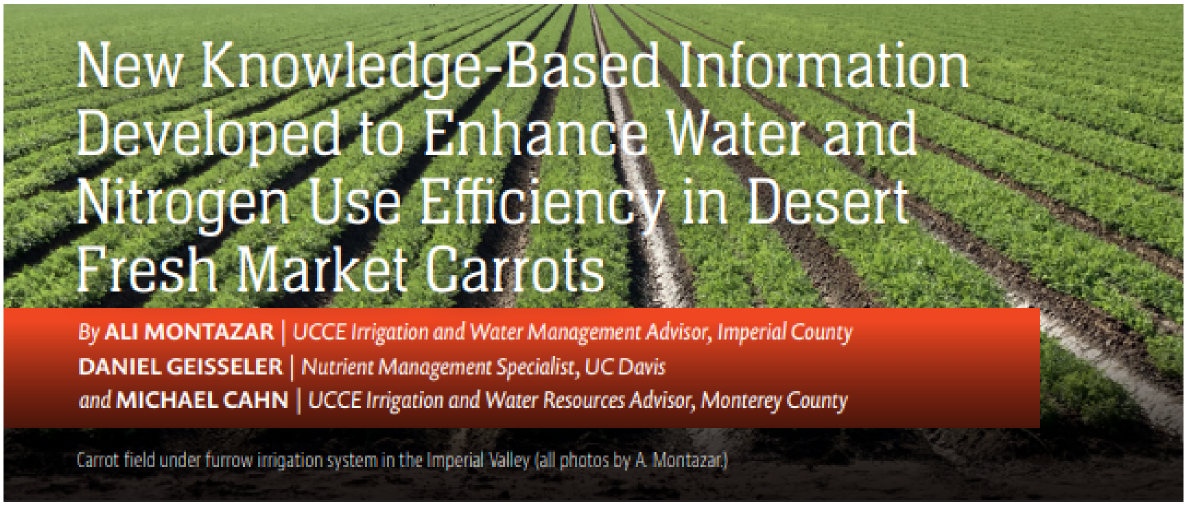
Citation: Montazar, A.; Geisseler, D.; Cahn, M. Spatial Variability of Nitrogen Uptake and Net Removal and Actual Evapotranspiration in the California Desert Carrot Production System. *Agriculture* **2021**, *11*, 752. https://doi.org/10.3390/agriculture11080752

Received: 12 July 2021
Accepted: 4 August 2021
Published: 7 August 2021

1. Introduction

Carrots (*Daucus carota* L.) are one of the major commodities in the low desert of California, with an average planted area of nearly 8500 hectares over the past decade [1]. Carrot is a cool-season crop that demands specific growing conditions and an adequate supply of mineral N and water for successful commercial production. Optimizing nitrogen and water management in carrot production is crucial for maximizing crop productivity and minimizing costs and nitrate leaching losses. Appropriate soil fertility and uniform soil water availability are critical for good root formation [1,2]. Carrot roots are vulnerable to forking, which can be caused by over-applying N fertilizer [2]. Excessive watering increases the incidence of hairy roots, discourages good color formation, and may encourage disease incidence [3]. Severe drying and wetting cycles result in the significant splitting of roots.



New Knowledge-Based Information Developed to Enhance Water and Nitrogen Use Efficiency in Desert Fresh Market Carrots

By **ALI MONTAZAR** | *UCCE Irrigation and Water Management Advisor, Imperial County*
DANIEL GEISSELER | *Nutrient Management Specialist, UC Davis*
and **MICHAEL CAHN** | *UCCE Irrigation and Water Resources Advisor, Monterey County*

Carrot field under furrow irrigation system in the Imperial Valley (all photos by A. Montazar.)

CARROTS ARE ONE OF THE 10 MAJOR commodities in Imperial County, with an average acreage of nearly 16,000 over the past decade. The farm gate value of fresh market and processing carrots was about $66 million in 2019. In the low desert region, fresh market and processing carrots are planted from September to December for harvest from January to May. Most carrots are typically sprinkler irrigated for stand establishment and subsequently furrow irrigated for the remainder of the growing season. However, there are fields that are irrigated by solid set sprinkler systems the entire crop season.

Carrot is a cool-season crop that demands specific growing conditions and effective use of nitrogen (N) and water applications for successful commercial production. N and water management in carrot is crucial for increasing crop productivity and decreasing costs and nitrate leaching losses. The N needs of carrots for optimum storage root yield depends on the climate, soil texture and conditions, residual soil N from the previous season and irrigation management. There is not enough research on N management to free local growers of the worry associated with being short on the amounts applied, which may cause a loss in yield and profitability. The industry needs reliable information on N and consumptive water use of carrots to optimize irrigation and N management, enhance water and nitrogen use efficiency and achieve full economic gains in a sustainable soil and water quality approach.

This study aimed to quantify optimal N and water applications under current management practices and to fill knowledge gaps for N and water management in carrots through conducting experimental trials in the low desert of California. This article presents some of the information developed for desert fresh market carrots.

Field Trials and Measurements

Field trials were conducted on fresh market carrot cultivars at the UC Desert Research and Extension Center (DREC) and four commercial fields in the low desert region during the 2019-20 and 2020-21 seasons (**Table 1, see page 10**). The sites represent various aspects of nitrogen applied (N applications ranged between 176 and 272 lbs ac^{-1}), irrigation water applied (varied from 1.6 to 2.9 ac-feet/ac), irrigation systems (three fields under sprinkler irrigation and two fields under furrow irrigation) and soil types (sandy loam to silty clay loam).

The DREC trials consisted of two irrigation regimes and three nitrogen scenarios (**Fig. 2**). At the commercial sites, due to logistical limitations, the measurements were carried out from five sub-areas selected (50 feet x 50 feet) in an experimental assigned plot (400 feet x 400 feet) with a homogeneous soil type, which was the dominant soil at the site. These areas represented common irrigation and N fertilizer management practices followed by growers.

The actual consumptive water use (actual crop evapotranspiration (ET)) was measured using the residual of the energy balance method with a combination of surface renewal and eddy covariance equipment (fully automated ET tower, **Fig. 3**). As an affordable tool to estimate actual crop ET, Tule Technology sensors were also set up at all experimental sites. The Tule ET data were verified using the ET estimates from the fully automated ET tower. Canopy images were taken on weekly to a 15-day basis utilizing an infrared camera (NDVI digital camera) to quantify crop canopy coverage over the crop season. Actual soil nitrate content (NO_3-N) at the crop root zone (one to five feet) and the total N percentage in tops and roots were determined pre-seeding, post-harvest and monthly over the season. Plant measurements were carried out on 40-plant samples collected randomly per replication of each treatment/sub-area, and deter-

Continued on Page 10

Experimental Site	Seeding (first irrigation) Date	Harvest Date	Irrigation Practices
DREC-1	Oct 11, 2019	Mar 18, 2020	Sprinker
DREC-2	Oct 14, 2020	Mar 21, 2021	Sprinker
C1	Oct 24, 2019	Mar 30, 2020	Sprinker
C2	Oct 2, 2019	Mar 19, 2020	Furrow
C3	Oct 4, 2019	Mar 17, 2020	Furrow
C4	Oct 2, 2020	Apr 12, 2021	Sprinker

Table 1: General information for the experimental sites. Plants were established using sprinkler irrigation at all sites.

Continued from Page 8

minations were made on marketable yield and biomass accumulation. Fresh weight and dry weight of roots and foliage were measured on a regular basis.

Findings and Recommendations

Irrigation Management

The common irrigation practice in carrot stand establishment in the low desert is to irrigate the field every other day using sprinkler systems during the first two weeks after seeding. Carrots germinate slowly, and hence, the beds need to be kept moist to prevent crusting. A comparison between the averages of applied water and actual consumptive water use for a 30-day period after seeding suggested that carrots are typically over-irrigated during plant establishment. An average of 3.8 inches was measured as actual consumptive water use for this period across the experimental sites (**Fig. 4, see page 12**), while the applied water varied from two to three times of this amount.

The results clearly demonstrated that the carrot sites had variable actual consumptive water uses depending upon early/late planting, irrigation practice, length of crop season, soil type and weather conditions. For instance, site C-4 was a sprinkler irrigated field with a dominant soil texture of sandy clay loam where the carrots were harvested very late 193 days after seeding (DAS). The seasonal consumptive water use was 19.2 inches at this site (**Fig. 4, see page 12**). Our results show that the seasonal crop water use of fresh market carrots is nearly 16.0 inches for a typical crop season of 160 days with planting in October. Approximately 50% of crop water needs occurred during the first 100 days after seeding and the other 50% during the last 60 days before harvest. Crop canopy model developed in this study demonstrated that fresh market carrots reach 85% canopy coverage by 100 days after seeding.

The amount of water that needs to be applied in an individual field depends on crop water requirements and the efficiency of the irrigation system. Assuming an average irrigation efficiency of 70%, the approximate gross irrigation water needs of carrot fields in the low desert would be 2.0 ac-feet/ac (pre-irrigation is not included) for a 160-day crop season. Pre-irrigation along with proper irrigation scheduling over the season may effectively maintain crop water needs and salinity in carrots.

Water stress should be avoided throughout the carrot growing cycle. The critical period for irrigation is between fruit set and harvest. Sprinkler irrigation may be considered as a more effective irrigation tool when compared with furrow irrigation. More frequent and light irrigation events are possible by sprinkler irrigation. Over-irrigation of carrot fields increases the incidence of hairy roots, and severe drying and wetting cycles result in significant splitting of roots. Sprinklers also reduce salinity issues which is important since carrots are very sensitive to salt accumulation.

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Figure 2: The DREC trials consisted of two irrigation regimes and three nitrogen scenarios.

Figure 3: Monitoring stations in one of the commercial experimental sites.

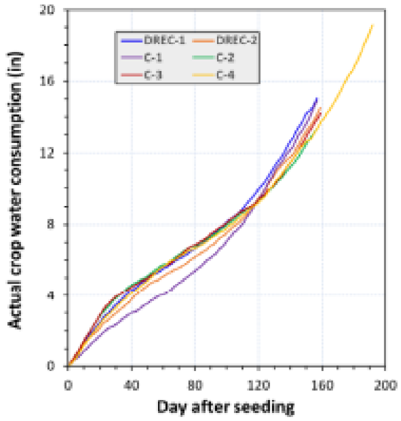

Figure 4: Cumulative actual crop water consumption (actual ET) at each of the experimental sites. Surface renewal actual daily ET is reported here.

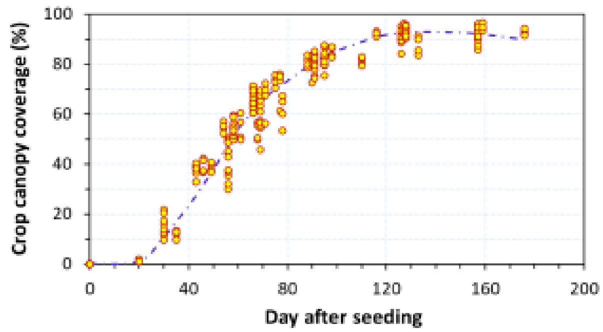

Figure 5: Canopy development curve for the low desert fresh market carrots over the growing season.

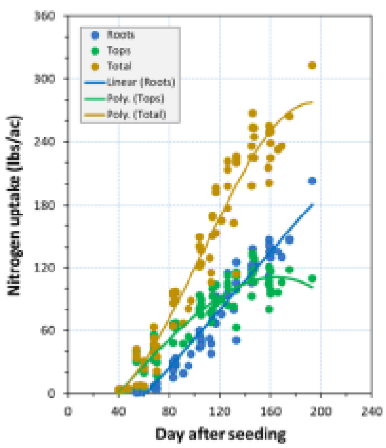

Figure 6: N accumulation trends in storage roots, tops and total (plants) over the growing season at the experimental sites.

Continued from Page 10

Nitrogen Management

The results demonstrated that a wide range of N accumulated both in roots and tops at harvest (**Fig. 6**). For instance, a total N content of 312.9 lbs ac^{-1} was observed in a fresh market carrot field with a long growing season of 193 days, including 202.9 and 110.0 lbs N ac^{-1} in roots and tops, respectively. The total N accumulated in plants (roots + tops) was less than 265 lbs ac^{-1} in the other sites.

A linear regression model was found for the total N uptake in roots after 60 to 73 DAS without declining near harvest (**Fig. 6**). Small, gradual increases in N contents of roots were observed until about 65 DAS. This suggested that N begins to accumulate at a rapid rate between 65 and 80 DAS; however, the period of rapid increase could vary depending on early (September) or late (November) plantings. N uptake in tops increased gradually following a quadratic regression, and in most sites levelled off or declined slightly late in the season. Although the N accumulated in tops appeared to drop down or level off in most sites beyond 120 to 145 DAS, the N content decline occurred after DAS 155 at site C-4 with a longer growing season.

These findings suggest that a total N accumulation of 260 lbs ac^{-1} occurred by 160 DAS, with 145 lbs ac^{-1} in roots and 115 lbs ac^{-1} in tops. Across all sites, nearly 28% of seasonal N accumulation occurred by 80 DAS (**Fig. 6**) when the canopy cover reached an average of 67% (**Fig. 5**). The large proportion of this N content was taken up during a 30-day period (50 to 80 DAS). The results also suggest that nearly 50% of the total N was taken up during a 50-day period (80 to 130 DAS). This 50-day period appears to be the most critical period for N uptake, particularly in the storage roots, when carrots developed the large canopy and the extensive rooting system. The majority of N is taken up during the months of December to February, and, hence, proper N fertility in the effective crop root zone is essential during this period. For a 160-day crop season, 22% of N uptake could be accomplished over the last 30 days before harvest.

Carrots have a deep rooting system that allows for improved capture of N from deep in the soil profile. The fibrous roots were present at the depth of five feet below the soil surface at site DREC-2 (**Fig. 7**). There is a risk of leaching soil residual N due to heavy pre-irrigation (a common practice for salinity management in the low desert) in late summer prior to land preparation. N is likely accumulated at the deeper depths by the beginning of the growing season, and consequently, there is a potential N contribution from the soil for carrots when the roots are fully developed. Since residual soil N contribution can be considerable in carrots, pre-plant soil nitrate-N assessment down to 60 cm depth could be a tool enabling farmers to improve N management and maximize yield and quality while minimizing economic and environmental costs.

Careful management of N applications in the low desert carrots is crucial because fertilizers are the main source of N, particularly due to low organic matter content of the soils and very low nitrate level of the Colorado River water. Knowing this fact, the soil NO_3-N contents pre-seeding and over the growing season at different sites revealed that none of the sites had N deficiency during the crop season, and consequently, the practice of splitting N applications, as done by the farmers (applying 9% to 15% of total seasonal N as pre-plant and the remainders through irrigation events over the season), was likely effective in most cases. It appears that the practice of 15% to 30% seasonal N applications though irrigation events 45 to 70 DAS has similar effectiveness to sidedress N applications.

Within the range of N application rates examined at the experimental sites, there were no significant relationships between carrot fresh root yield and N application rate, although the results suggested a positive effect of N application on carrot yield. Sufficient N availability in the crop root zone over the growing season and the lack of significant yield response to N applications demonstrate that N optimal rates could be likely less than the applied amounts in most sites. Adequate nitrogen and water applications reduce costs and help prevent leaching, while excess N may lead to excessive N storage in the roots, which may be a concern for processing carrots. Integrated optimal N and water management needs to be approached to accomplish greater N and water efficiency, and consequently keep lower rates beneficial to overall profitability.

Funding for this study was provided by California Department of Food and Agriculture (CDFA) Fertilizer Research and Education Program (FREP) and California Fresh Carrots Advisory Board.

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Figure 7: Carrot storage and fibrous roots system at site DREC-2.

NEEDS ASSESSMENT

The Latest Science-Based Information on Water and Nitrogen Best Management Practices for Low Desert Carrots

By Ali Montazar, Irrigation and Water Management Advisor, University of California Cooperative Extension, Imperial, Riverside and San Diego Counties

A better understanding of how carrot crops use water and nitrogen may ultimately improve carrot production in the low desert region of California.

Carrots are one of the 10 major commodities grown in Imperial County, California, with an average acreage of nearly 16,000 over the past decade, according to 2010-2019 Imperial County Agricultural Crop & Livestock Reports. The farm gate value of fresh market and processing carrots was about $66 million in 2019.

In the Imperial Valley, most carrots are typically sprinkler irrigated for stand establishment and subsequently furrow irrigated for the remainder of the growing season. However, there are fields that are irrigated by solid set sprinkler systems during the entire crop season (Fig. 1).

Nitrogen (N) and irrigation management in carrot production systems is critical for increasing the efficiency of crop production and decreasing costs and nitrate leaching losses. The N needs of carrots for optimum storage root yield depend on the climate, soil and residual soil N from the previous season. To accomplish greater nitrogen and water efficiency, more accurate crop water use information of carrots is required with respect to different soil types, carrot crops, weather and farming practices. Utilizing more accurate estimates of crop water consumption and N uptake may have a significant impact on water quality issues and on soil water and N availability, potentially increasing the economic sustainability of carrot production.

An ongoing study at the University of California particularly seeks to quantify and fully understand carrot production issues under current management practices, and to fill knowledge gaps for nitrogen and water management in carrots through conducting experimental trials in the low desert of California.

Field Experiments

Field experiments were conducted at the University of California Desert Research and Extension Center (DREC) located in Holtville, California, during the 2019-2020 crop season (Fig. 2). The trial consisted of two sprinkler irrigation regimes and three nitrogen strategies. In addition, measurements were conducted in five commercial fields in the Imperial Valley with various soil types and under sprinkler and furrow irrigation. Stand establishment was accomplished by sprinklers at the experimental sites.

The actual crop water consumption (actual crop ET; ET stands for evapotranspiration) was measured using the residual of the energy balance method with a combination of surface renewal and eddy covariance equipment (fully automated ET tower in Fig. 3). As an affordable tool to estimate actual crop ET, Tule Technology sensors were also set up at all experimental sites. The Tule ET data were verified using the ET estimates from the fully automated ET station. Soil moisture sensors were installed at multiple depths to monitor soil water potential on a continuous basis (Fig. 3). In both the DREC trial and the commercial sites, actual soil nitrate content and the total N in the plants (tops and roots) were measured several times per crop season.

Results

The common irrigation practice in carrot stand establishment is to irrigate the field every other day during the first two to three weeks after seeding. Carrots germinate slowly, and hence, the beds need to be kept moist to prevent crusting. A comparison of applied water and crop water consumption indicates that the carrot fields could be overirrigated by three times of crop water requirements during the stand establishment.

A wide range in the length of the crop season (seeding through harvest) was observed, ranging from a 128-day period in a processing carrot to a 177-day period in a fresh market carrot. The seasonal crop water consumption varied between 12.5 inches and 16.6 inches at the experimental sites (Fig. 4a). The results clearly demonstrate that carrot fields may have variable irrigation water requirements depending upon early/late planting, processing vs. fresh market, irrigation practices, length of crop season and soil type. A peak daily crop water use of 0.21 inches on March 23, 151 days after planting, was observed in a fresh market carrot field (Fig. 4b).

Water stress should be avoided throughout the carrot growing cycle. The critical period for irrigation is between fruit set and harvest. Sprinkler irrigation may be considered as a more effective irrigation tool when compared with furrow irrigation. More frequent and light irrigation events are possible by sprinkler irrigation. Over-irrigation of carrot fields increases the incidence of hairy roots, and severe drying and wetting cycles result in significant splitting of roots. Sprinklers reduce salinity issues, which is important since carrots are very sensitive to salt accumulation.

The irrigation water that needs to be applied in an individual field depends on

Figure 1. *Solid set sprinkler (left) and furrow (right) irrigation systems water carrot fields in the Imperial Valley of California.*

Figure 2. *A monitoring station is set up in treatment I1N1 in a trial at the University of California Desert Research and Extension Center.*

Figure 3. *A fully automated ET tower is seen in the photo on the left. A multi-depths soil moisture sensor monitoring station equipped with Tule sensor is pictured on the right.*

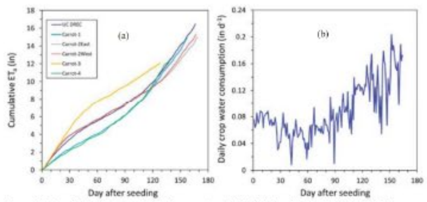

Figure 4. *Cumulative actual crop ET in the experimental fields (a) and daily actual crop ET at the fresh market Carrot-2East site (b)*

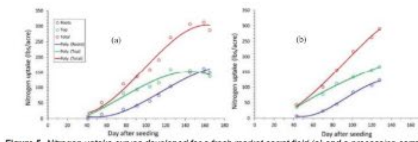

Figure 5. *Nitrogen uptake curves developed for a fresh market carrot field (a) and a processing carrot field (b)*

Figure 6. *Carrot tops and plant residues remain in a fresh market carrot field in the Imperial Valley of California after harvest.*

crop water requirements and the efficiency of the irrigation system. Assuming an average irrigation efficiency of 70 percent, the approximate gross irrigation water needs of carrot fields in the low desert would be 1.5 - 2.1 ac-feet/ac (pre-irrigation is not included). Pre-irrigation along with proper irrigation scheduling over the season may effectively maintain crop water needs and salinity in carrots.

The preliminary results of this study demonstrate a notable amount of N uptake both in the roots and tops at harvest time. For instance, a total N content of 286 lbs./acre in plants grown for a period of 164 days (149- and 137- lbs./acre in roots and tops, respectively) was observed in a fresh market carrot field (Fig. 5). The total N content was 297 lbs./acre in processing carrots (123 lbs./acre in roots and 174 lbs./acre in tops). Total N uptake in the roots and tops was similar, with rapid increase beginning 55 days and 45 days after seeding, respectively. The rate of increase in total N content in the roots did not decline near harvest in any of the experimental sites, while it declined in the tops for fresh market carrots beginning 125 days after seeding.

Nearly 50 percent of seasonal N accumulated in the tops and the roots occurred at 85-90 days after planting when the canopy is fully developed. An effective nitrogen fertilizer application could be splitting N application into 10-12 percent at planting, 30-35 percent as side dressing (in case of furrow irrigation) and the remainder through irrigation events. Assuming a 150–170-day period as a carrot crop season, it is recommended to apply the total nitrogen fertilizers by 15-20 days before harvest.

The results of this study illustrate that 45-55 percent of total N accumulated in the carrot plants is left in the fields as residual soil N right after harvest which could contribute as a source of nitrogen for the following season (Fig. 6). Further work is needed to quantify what fraction of N provided by the plant residues potentially contributes to the following season, particularly since there is a risk of leaching a portion of residual N due to heavy pre-irrigation in the late summer during land preparation.

Irrigation and Nitrogen Management Strategies

By Ali Montazar, Michael Cahn and Jaspreet Sidhu, University of California Cooperative Extension; and Daniel Geisseler, University of California - Davis

Water and nitrogen (N) management in carrots is critical for increasing efficiency of crop production by decreasing costs and nitrate leaching losses. This will become increasingly important with high fertilizer prices, and as water quality and quantity concerns continue to increase. To maximize yield and quality, carrots need a sufficient level of N in the soil. Matching N fertilizer applications with carrot N uptake, and water applied with crop water requirements can optimize N and water use efficiency, as well as crop yield and quality.

A study was conducted to gain information on improving and promoting adoption of management practices that optimize N and irrigation water use efficiency in California carrot production systems.

Field Experiment

A two-year study (October 2021 through March 2023) was conducted at the University of California Desert Research and Extension Center in Holtville, California (Fig. 1). The experiment consisted of three N fertilizer strategies (N1, N2, N3) under two irrigation regimes (I1, I2). The trials were arranged in a randomized complete block with split plot arrangement over four replications. Each sub-plot included 12 beds 40 inches wide and 60 feet long. Ten lines of Choctaw fresh market carrots were seeded in each bed.

The dates of first irrigation and harvest were Oct. 8, 2021, and March 17, 2022, for the 2021-22 trial, respectively. These dates were Oct. 4, 2022, and March 14, 2023, for the 2022-23 trial, respectively. Solid set sprinklers were used to irrigate the trials throughout both seasons. The study field of the 2021-22 season had a sandy clay loam (top 1 foot) to sandy loam (1-3 feet) soil texture. The soil texture of the field in the 2022-23 season was silty loam at the top 2 feet and sandy loam below 2-foot depth.

The water applied to the irrigation treatments was monitored using magnetic flowmeters on a 30-minute basis (Fig. 2). Actual soil nitrate content (NO_3-N) and total N percentage in tops and roots were determined monthly through laboratory analysis. Preplant and post-harvest soil samples were taken from six depths (1-6 feet). At other sampling dates, soil was collected from the top three depths (1-3 feet). A composite soil sample was analyzed from each layer for NO_3-N content.

Canopy images were taken on a weekly to a 15-day basis utilizing an infrared camera to quantify crop canopy coverage over the crop seasons.

Plant measurement was carried out on 40-plant samples collected randomly per plot, and determinations of fresh and dry weights of roots and foliage were made on a regular monthly basis during the seasons. The plant measurement was conducted on 100-plant samples per plot at harvest.

Figure 1. A 2021-22 field trial evaluates nitrogen and irrigation water use efficiency in California carrot production systems.

Figure 2. Magnetic flow meters and data store and transfer equipment monitors water applied to a 2022-23 field trial.

Water and Nitrogen Applied

The seasonal water and N applications in the different irrigation regimes and N strategies are listed in Table 1. A preplant N fertilizer with monoammonium phosphate was broadcast at a rate of 280 lbs./ac over the entire trial area in both seasons. Urea ammonium nitrate (UAN-32) was injected into the sprinkler system to supply the remaining amount of N for each nitrogen treatment. The application rates varied from 140 to 235 lbs. N/ac in the 2021-22 season and from 145 to 217 lbs. N/ac in the 2022-23 season.

The amount of irrigation water was determined using the CropManage irrigation and nitrogen decision management tool (www.cropmanage.ucanr.edu) to provide 100 percent of crop water needs (ET or irrigation regime 1) and 25 percent more than crop water needs (125 percent ET or irrigation regime 2). The amounts of irrigation varied from 24.5 to 30.8 in. and from 23.6 to 29.7 in. in the 2021-22 and 2022-23 seasons, respectively (Table 1). The trends of water and N applications per event for the 2022-23 season can be found in Fig. 3.

Impact on Nitrogen Uptake

Data of this study reported in an earlier article suggested that nearly 50 percent of the total N in carrots is taken up during a 50-day period, 80-130 days after seeding. This 50-day period appears to be the most critical period for N uptake, particularly in the storage roots, when carrots developed the large canopy and the extensive rooting system. The findings also demonstrated that for a 160-day crop season in the low desert of California, 22 percent of N uptake took place over the last 30 days before harvest.

The highest N accumulation rates at harvest were associated with the N2 treatment under the I2 irrigation regime (273 lbs. ac^{-1}) and the N3 treatment under the I1 irrigation regime (281 lbs. ac^{-1}) in the 2022-23 season (Fig. 4). However, nitrogen application rates had no statistically significant effect on total N uptake (roots and tops) and the N accumulated in roots. The N application rate had a clear and scientifically significant effect on increasing aboveground foliage (tops), which could be a reason for greater nitrogen uptake at the higher rate of N applied.

The results provide evidence for an overall effect of the interaction of irrigation regime and nitrogen management strategy on the total N accumulation in carrots (roots and tops) even though the irrigation regime as an individual driver had no significant effect on the N accumulation (neither the total nor tops or roots). It is likely relevant to the range of water application rates. The 25 percent over-irrigation couldn't have a considerable impact on leaching nitrate within a silty loam soil type. A higher amount of excessive water through a more aggressive over-irrigation scenario (for instance, 150 percent ET) could influence the N uptake differently. The results of nitrogen accumulation were basically consistent within the two seasons.

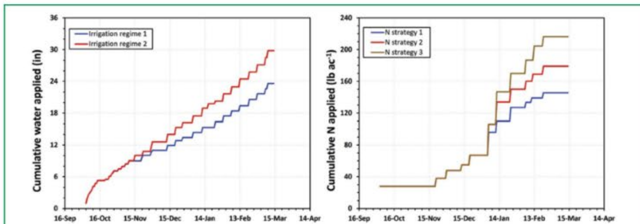

Figure 3. Cumulative water and nitrogen (N) applied in each of the irrigation regimes and nitrogen strategies over the 2022-23 season

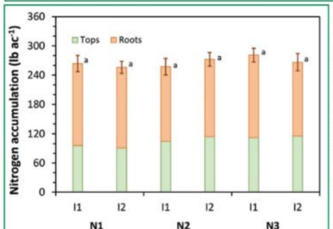

Figure 4. Mean nitrogen (N) uptake distribution in carrot roots and tops affected by water regimes and nitrogen application rates in the 2022-23 season. The bars demonstrate the standard error of root yield values. Fresh root yields with different letters significantly differ ($p < 0.05$) by Tukey's test.

Impact on Carrot Fresh Roots

Although no statistically significant impacts were found from both irrigation and N application rates on the fresh root yield in the 2022-23 season, N application statistically affected root yield in the 2021-22 season (Fig. 5). The lowest fresh root yield (40.8 t ac^{-1}) was observed in the I2N1 treatment (irrigation regime 2 and an N application rate of 140 lbs. ac^{-1}). A lower soil residual nitrate content could have contributed to a lower root yield in

Table 1. Seasonal water and nitrogen (N) application rates in the study seasons

	2021-22 season	2022-23 season
N application (lb. N/ acre)	N1 = 140	N1 = 145
	N2 = 185	N2 = 180
	N3 = 235	N3 = 217
Water application (in)	I1 = 24.5	I1 = 23.6
	I2 = 30.8	I2 = 29.7

this specific treatment in the 2021-22 season. A greater mineral N content in the top 2 feet of soil was determined right before planting in the 2022-23 season (106 lbs. N/ac) than in the 2021-22 season (77 lbs. N/ac).

Since residual soil N can contribute considerably to the N requirement in carrots, preplant soil nitrate-N assessment down to 2-ft. depth is a tool that can enable growers to improve N management and maximize yield and quality while minimizing economic and environmental costs.

The findings suggested insignificant difference of fresh root yields impacted by the interaction of irrigation regime and N strategy within the range of application rates in both seasons. Different results could be obtained in a field that is irrigated more than the I2 treatment (> 125 percent of CropManage recommendation), has a low residual nitrate content or/and has a sandy textured soil.

Conclusions

Nitrogen and irrigation water must be effectively used in mineral soils to produce carrots with high yield and with minimal environmental impact. In the low desert of California, the majority of N is taken up during the months of December to February, and hence, proper N fertility in the effective crop root zone is essential during this period. An integrated optimal N and water management plan needs to be followed to achieve high N and water efficiency, and consequently overall profitability.

Positive impact of N application rate on carrot root yield was observed, but statistically no significant relation was found. The findings of this study suggested that N application rates greater than 145 lbs. ac^{-1} do not have a significant impact on carrot root yield in a well-managed irrigated field with a silty loam soil texture (above 2 ft.) to sandy loam (below 2 ft.). However, the fact that more N was taken up in the crop than applied for the N1 and N2 treatments would suggest that the residual nitrate in the soil from the past season contributed to the N nutrition of the crop. Higher N rates are likely necessary in over-irrigated carrot fields (receiving more than 125 percent of crop ET), or fields with a low residual nitrate content. This is because improving N use efficiency is closely associated with water use efficiency. On sandy textured soils, water management can be especially important for achieving high N use efficiency in carrots. Carrots need variable seasonal water application that depends on planting time, length of season, variety, soil types and irrigation efficiency. In this study, we used CIMIS reference evapotranspiration data and a crop coefficient model applied through CropManage online software to estimate water requirements of carrot before each irrigation.

Growers are encouraged to try using a reduced N rate (10-20 percent lower than their current practice) on a small field to evaluate how it fits their specific farming practices before they adopt it on a widespread basis. Analyzing soil samples for residual soil nitrate early in the season (after the pre-irrigation) and in-season soil nitrate and leaf tissue analyses can provide confidence in the new practices and allow for corrective measures. Information on using the soil nitrate quick test can be found at www.cdfa.ca.gov/is/ffldrs/frep/pdfs/nitratequicktestweb.pdf. Sufficient N availability in the crop root zone over the growing season and the lack of significant yield response to N application within the range of N application rates in this study suggested that N optimal rates could be likely less than 180 lbs. ac^{-1} in the low desert of California.

Authors' note: *Funding for this study was provided by the California Department of Food and Agriculture (CDFA) - Fertilizer Research and Education Program (FREP) and the California Fresh Carrot Advisory Board.*

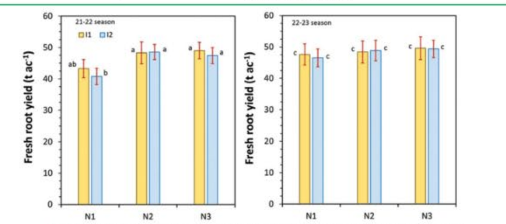

Figure 5. Mean fresh carrot root yields as affected by water regimes and nitrogen (N) application rates over the study seasons. The bars demonstrate the standard error of root yield values. Fresh root yields with different letters in each season significantly differ ($p < 0.05$) by Tukey's test.

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