Determination of Root Distribution and Physiological Parameters of Nitrogen Uptake in Almonds to Optimize Fertigation Practices

Project No.: **13-PREC5-Brown**

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Objectives:

- Determination and characterization of patterns and biological dynamics (K_m, V_{max}, $C_{min/max}$) of tree nutrient uptake and the relationship to soil nutrient concentration, tree demand and time.

- Determination of almond root phenology and characterization of root distribution and uptake activity as influenced by irrigation source, irrigation management and plant characteristics.

- Determine the explicit nitrogen uptake and demand dynamics for almond. Integrate this information into the model (in collaboration with ongoing Brown project).

- Demonstrate the efficacy of the approach in a field setting.

Interpretive Summary:

Optimal fertilization practice can only be developed if knowledge of the 4 R’s (right source, right rate, right place, and right time) is explicitly developed for the almond production context. To optimize nutrient use efficiency in fertigated almond it is essential that fertilizers injected into irrigation system are provided at the optimal concentration and time to ensure that deposition patterns coincide with maximal root nutrient uptake. This project has been designed to provide critical information about root physiology and phenology and the interaction with soil nutrients and fertigation practices. Results from the N rate and fertigation management treatments indicate that root growth and longevity is dependent on current soil nutrient status, current plant nutrient status and current yield. In addition, different fertigation practices (pulsed or continuous fertigation) suggest that applying the equivalent amount of fertilizers more often and hence reducing its concentration at any single fertigation event may be a viable fertigation management strategy to increase efficiency and reduce groundwater contamination.

Materials and Methods:

In order to achieve the objectives proposed in this project, two experimental trials have been used contrasting different rates of nitrogen (N), fertigation methods and irrigation methods.

1. Nitrogen rate experiment. The trees used in this proposed experiment have been selected from among those currently under investigation in related Almond Board projects (Brown/Smart/Sanden/Hopmans). The orchard is a high producing 13 year old Nonpareil/Monterey planting located south of Lost Hills in Kern County. The existing experiments provide preliminary individual tree data on yield, soil and plant water (neutron probe and plant based), plant nutrient status (5 in-season leaf samples), tree nutrient demand (sequential crop estimation and determination), leaf area index and photosynthesis and Et_0. The ongoing project of Brown has already established very clear differences in crop yield and nitrogen demand and represents an ideal field site for this work.

The treatments are described in **Table 1**.

Table 1. Treatments utilized in the current project. Selected trees within RCBD with 6 x 15 tree replicates per treatment.

Treatment	**N source**	**N amount (lbs/ac)**	**K source**	**K amount (lbs K/ac)**
A	UAN32	125	60% SOP / 40% KTS	200
B	UAN32	200	60% SOP / 40% KTS	200
C	UAN32	275	60% SOP / 40% KTS	200
D	UAN32	350	60% SOP / 40% KTS	200

Twenty minirhizotron access tubes were installed in the ongoing experiment to follow root phenology (root flushes, root lifespan, growth, etc.) over multiple seasons under four fertilization regimes. Root images have been taken during the 2011, 2012 and 2013 seasons on a 2 week basis and images have been analyzed recording number of roots, color, diameter and length. Analysis of these images was performed at the end of each season.

In addition, a total of 160 root bags filled with media were installed in the different treatments and N uptake was measured in excised roots. The relationship between the parameters of root N uptake and tree demand has been determined and correlated with yield and N content by leaf and nut sampling at harvest.

2. Fertigation method experiment. The effect of fertigation technique (pulsed, continuous, drip, microjet) was examined in a subset of trees in the same orchard as above (**Table 2**) established in 2011.

Table 2. Fertigation treatments in the ongoing project. Selected trees within RCBD with 4 x 7 tree replicates per treatment.

Treatment	N source	K source	Irrigation Method	Fertilization method
E	100% UAN32	100% SOP	Fanjet	4 fertigation events / year
F	100% UAN32	60% SOP / 40% KTS	Fanjet	Continuous (fertilization in each irrigation
G	100% UAN32	100% SOP	Drip	4 fertigation events / year
H	100% UAN32	100% SOP	Drip	4 fertigation events / year

In this experiment an additional 20 minirhizotron access tubes were installed in order to determine root phenology (root flushes, root lifespan, growth, etc.). Root images have been taken during the 2011, 2012 and 2013 seasons on a 2 week basis and images have been analyzed recording number of roots, color, diameter and length.

In addition, 80 soil solution access tubes (SSAT, a.k.a. “lysimeters”) have been installed in each treatment at 2 depths (150 and 250 cm) in order to measure nitrate (NO_3) leaching and transport through the soil profile throughout the season.

Individual trees have been analyzed for leaf nutrient analysis, yield, nut size and crack out percentage and contrasted among treatments (see results section).

Results and Discussion:

Nitrate Uptake by roots

Fine roots from each treatment in experiment 1, were isolated, excised and then incubated in solutions of different NO_3 concentration for 30 minutes. The external concentration (i.e. soil solution concentration) was modified from the previous sampling year to more realistic conditions (i.e. actual NO_3 soil solution concentration), and ranged from 0.05 to 7.5 $mmol \cdot l^{-1}$ of $N\text{-}NO_3$ (0.42 to 100 ppm of $N\text{-}NO_{3)}$. According to literature, root uptake of fine roots will depend mostly on the concentration of the external solution as well as the demand of NO_3 by the plant (i.e. plant N status). Preliminary results from this experiment are shown in **Figure 1**. When roots where incubated in solutions from a low range concentration of 0.05 to 0.5 $mmol \cdot l^{-1}$ of $N\text{-}NO_3$ (0.42 to 3.50 ppm of $N\text{-}NO_3$), all of the treatments showed an increase in uptake followed by a saturation at the end of this range; however, low N treatments exhibited a higher uptake capacity than the high N treatments, with no significant difference between treatments. This results suggests that N starved trees may up-regulate N uptake and can access N from lower NO_3 concentrations than trees with sufficient N content. At higher external $N\text{-}NO_3$ concentrations, ranging from 0.5 to 7.5 $mmol \cdot l^{-1}$ of $N\text{-}NO_3$ (7.01 to 14.01 ppm of $N\text{-}NO_3$) uptake rates significantly increased in comparison with lower external concentrations. In this case, low N trees exhibited lower uptake capacity than high N status trees. These results suggest that roots in almond trees may be more efficient at acquiring N at a specific range of external N concentration. Nitrate concentrations in the root zone can be controlled within a specific range by fertigation management through split applications during the season. Further research has to be conducted in this field to determine the adequate concentration to ensure optimal N uptake and reduce N losses. While this project has determined that low concentration nitrate applications may reduce uptake rates, there is no evidence of a detrimental effect of high nitrate concentrations on tree performance.

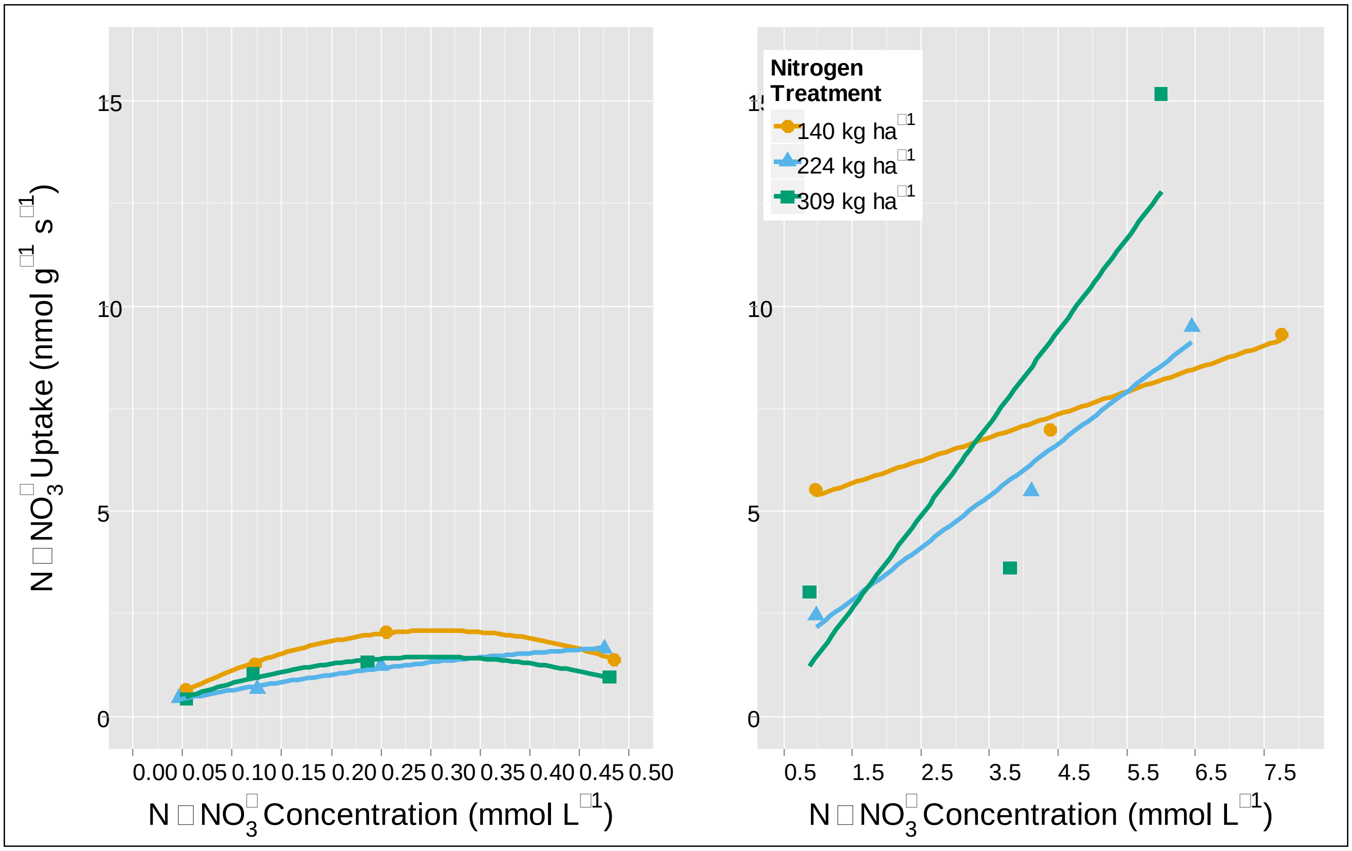

Figure 1. N-NO_3 uptake of almond roots at different N-NO_3 external concentrations

Results from the minirhizotron tubes installed in this experiment are shown in **Figures 2** and **3**, and show the pattern of root growth over the season. Irrespective of year, experiment or treatments, almond roots showed a consistent growth pattern with a dual cycle, with the majority of new roots being produced at two growth phases during the year (spring and fall). Spring root growth, occurring from mid-March to June was significantly higher than the fall growth, mainly occurring from mid-September to December. New root growth was very limited from June through September when maximal carbon demand for growing nuts occurred. There was very little root growth prior to leaf out with the predominant root growth period occurring after full leaf out. This result and results of prior experiments on whole tree nitrogen uptake verify that there is very little uptake of N from soil prior to leaf out in almonds.

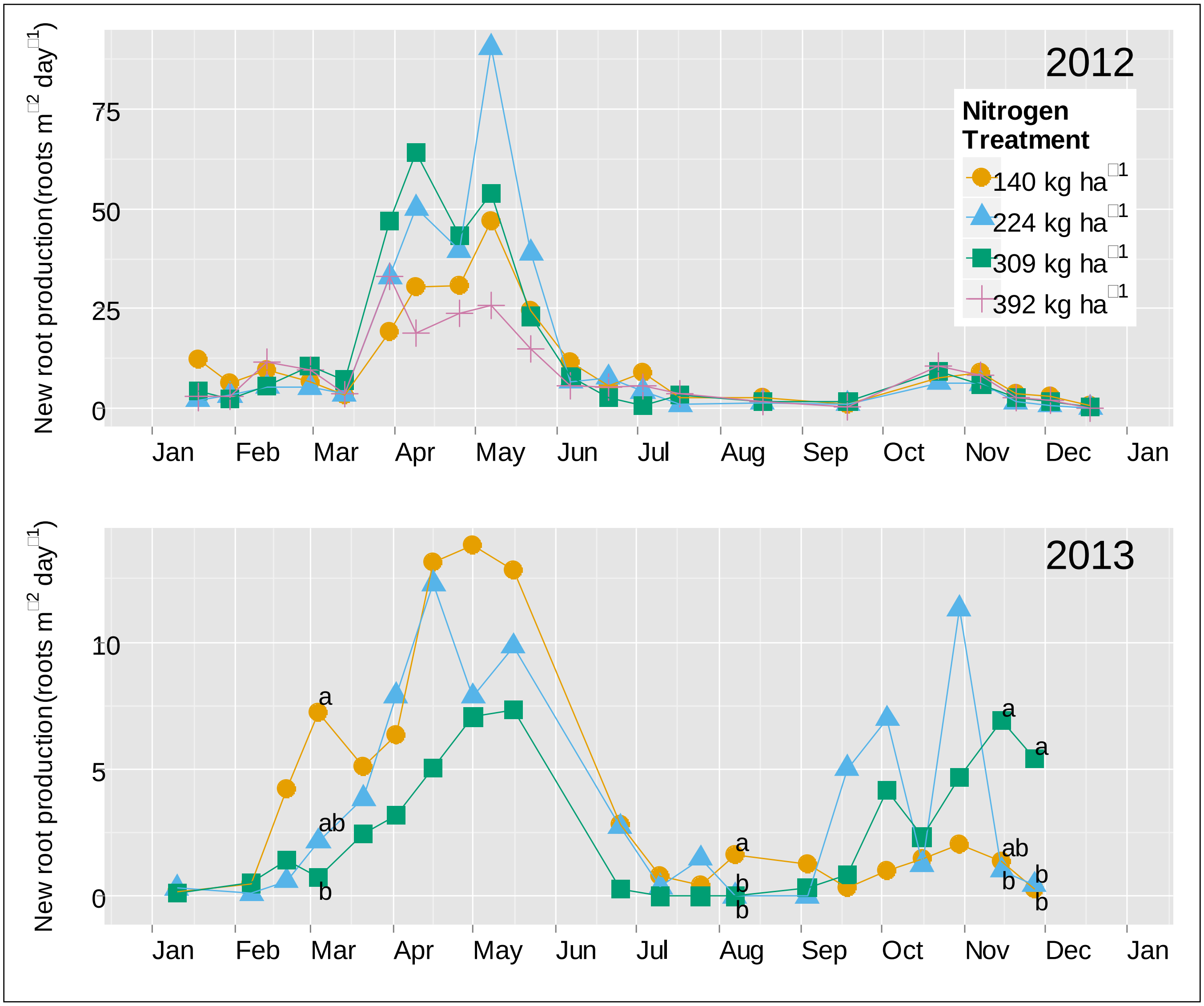

Figure 2. Number of new roots produced during the growing season in Experiment 1: N rate experiment. Note differences in scale used in these figures.

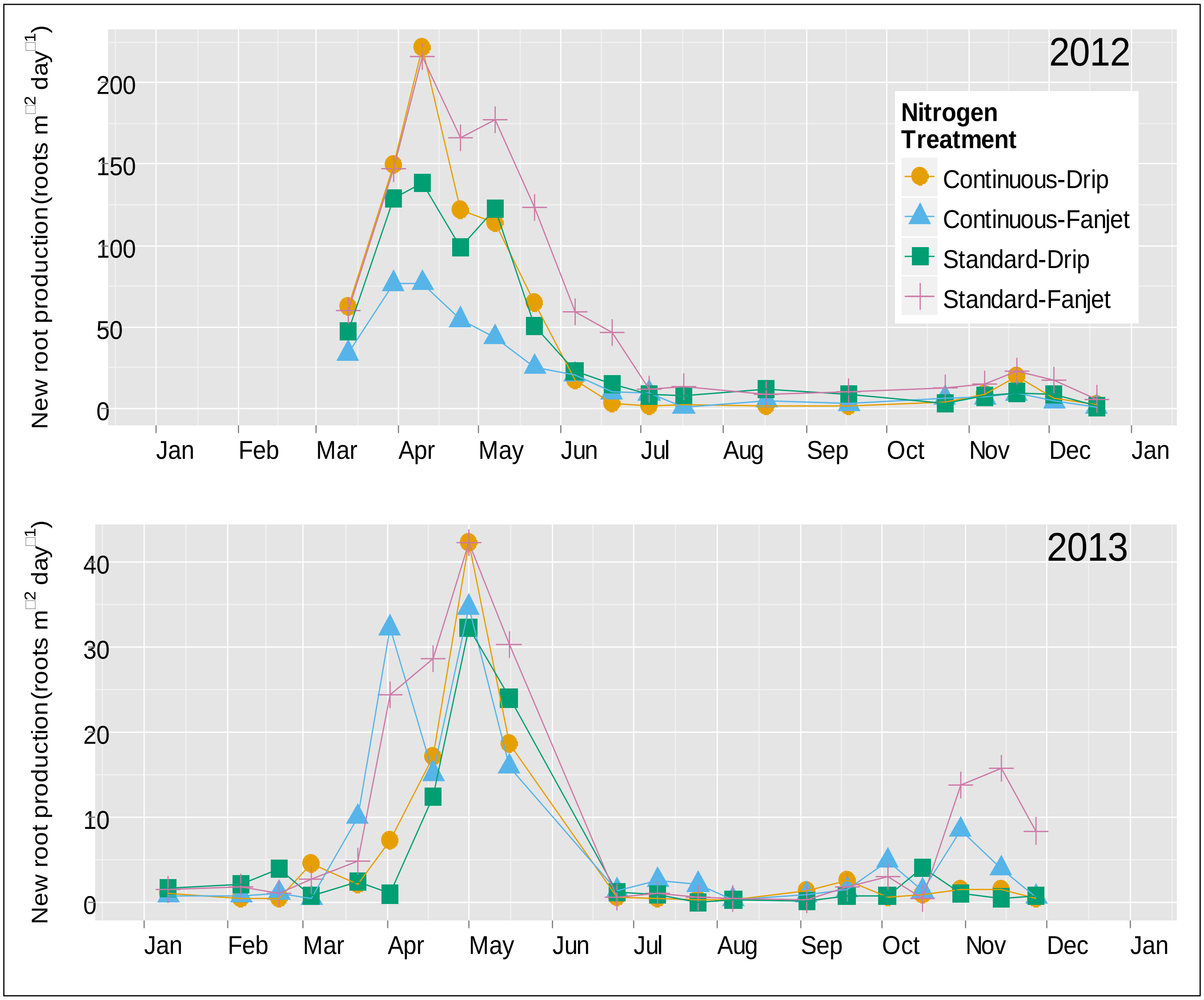

Figure 3. Number of new roots produced during the growing season in Experiment 2: Nitrogen Fertigation experiment.

While the pattern of new root growth did not vary from year to year or between experiments, the total amount of roots produced per season varied significantly from year to year (**Figure 4**). In 2011 the amount of new roots produced were significantly higher than in other years and may have been due to installation disturbance that promoted root growth on 2011, this increased growth immediately following installation has been widely reported in the literature. Root growth in 2012 was significantly greater than in 2013. The reason for this is uncertain; however it should be noted that yield in 2011 was exceptionally high (>4500 lbs acre) while in 2012 it was exceptionally low (900 lbs acre). The higher root growth in 2012 coincided with a very low fruit load suggesting that competition between shoots and roots defines the rate of new root growth. Interestingly this enhanced root growth occurred following an exceptionally high yield year during which tree carbohydrate reserves would have been severely depleted. This implies that new root growth is not dependent upon prior year carbohydrate storage. Similarly, the lower root growth observed in 2013 coincided with good fruit set, further suggesting that current fruit load influences root growth. To further explore the relationship between yield and root growth a simple linear regression between yield and total amount of roots was performed (**Figure 5**) and results showed that when yields are high, root production is low.

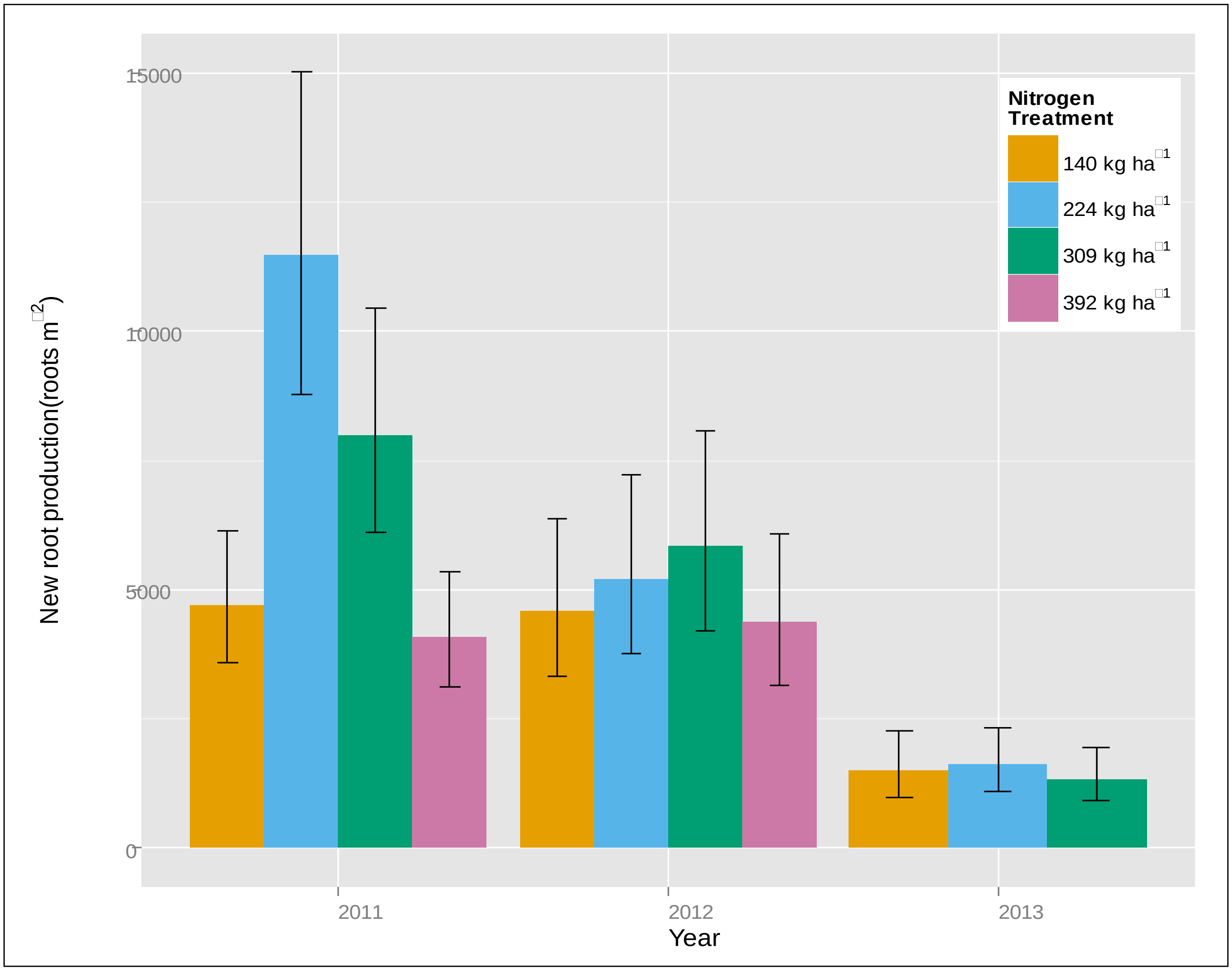

Figure 4. Total amount of new roots produced per year.

Nitrogen treatments and irrigation management strategies had no significant effect on root growth patterns suggesting that nitrogen supply is not a key determinant of root growth.

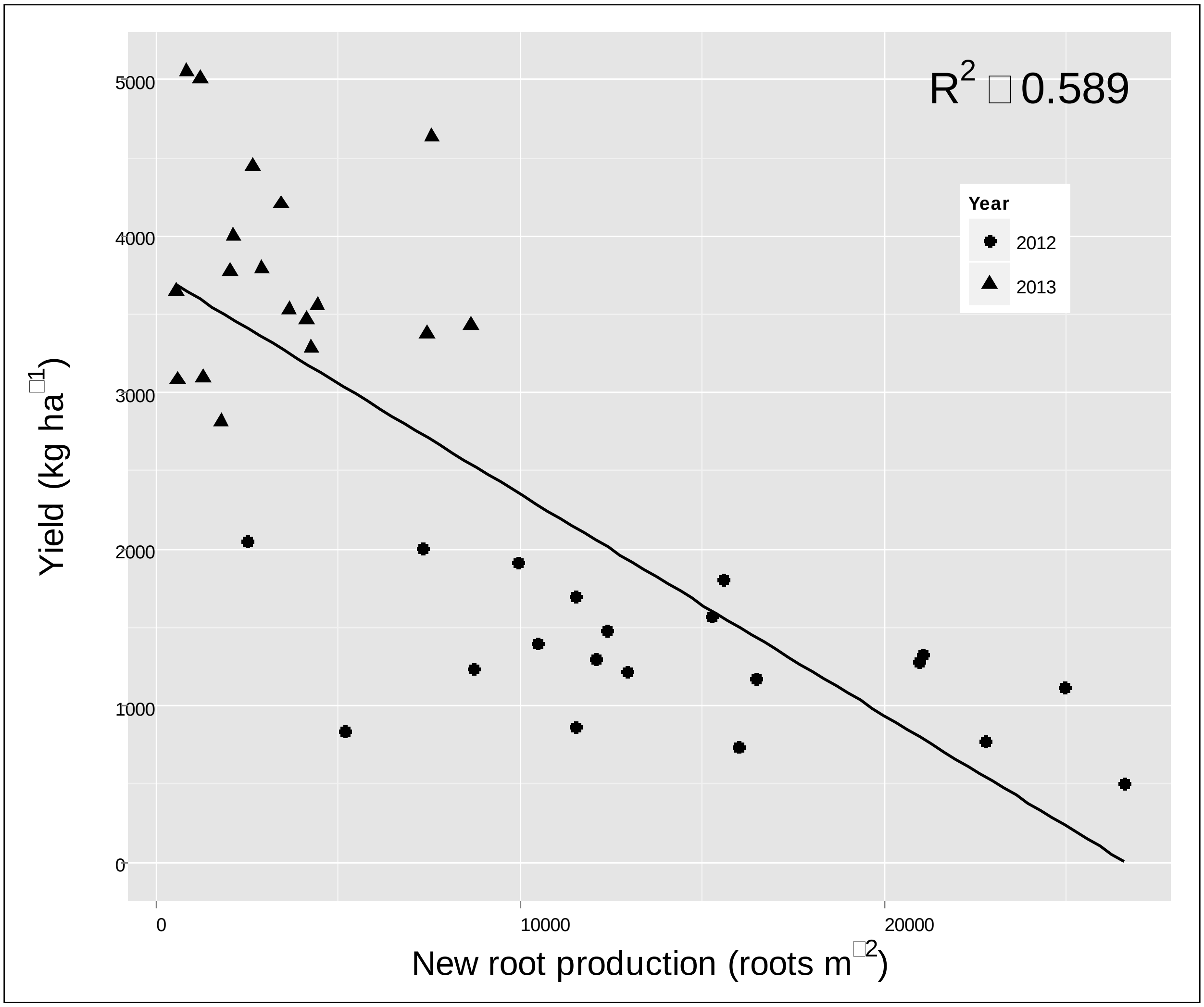

Figure 5. Relationship between almond yield and root production.

Patterns of root growth distribution by soil depth were determined by determining the number of new roots produce per 0.2 m interval (**Figure 6**). There was no significant difference in root distribution or density between treatments. Despite, the wide variation in the amount of roots between years (**Figure 6**, top graph), the percentage of roots per depth interval was similar. Virtually all the root growth is observed within 1.4 m depth, and 60-65% of the new roots are produced in between 0.2 and 0.6 m.

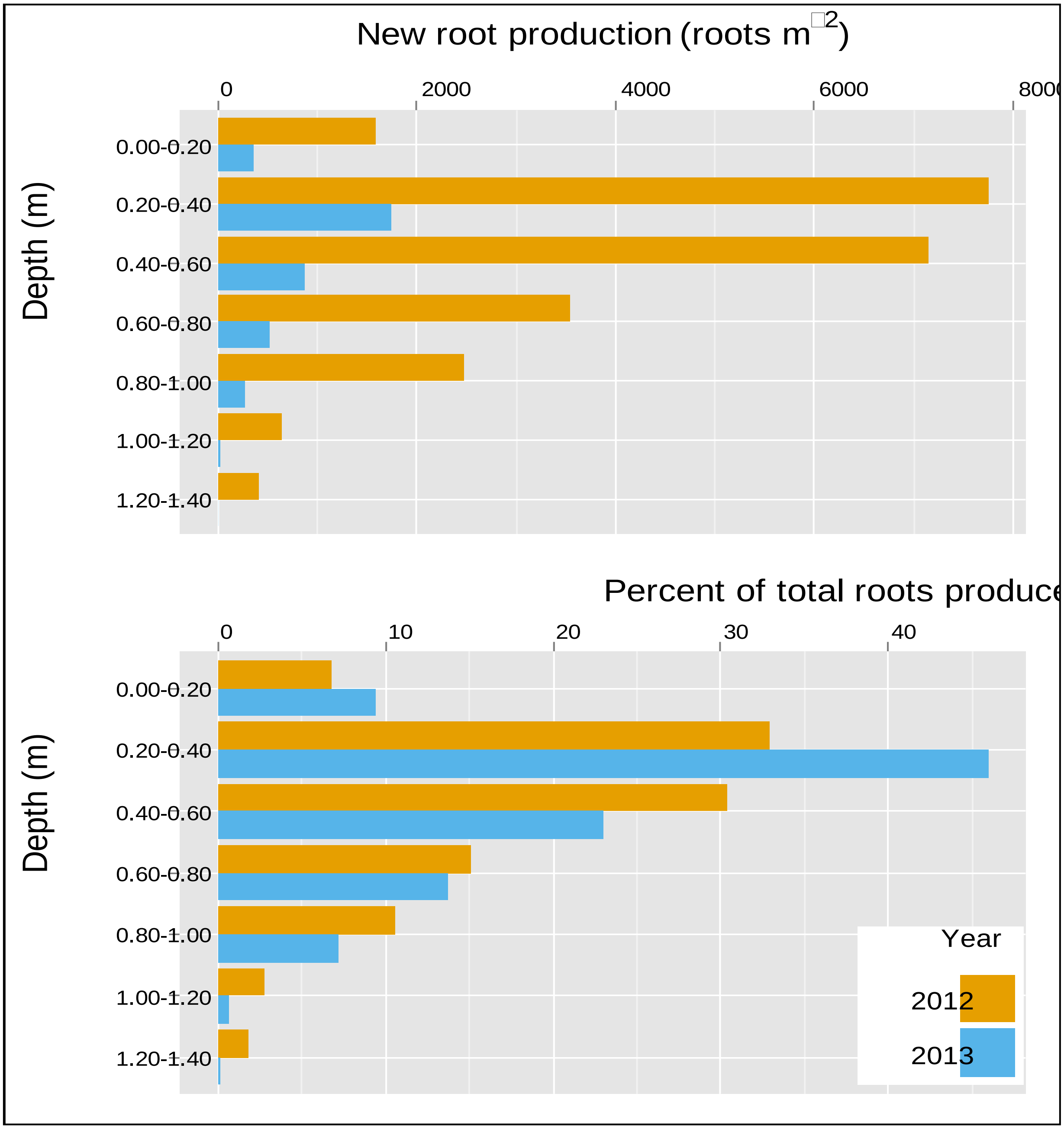

Figure 6. Vertical distributions of roots in soil depth intervals.

Due to the lack of adequate irrigation water in 2013 and 2014, no data from the installed soil solution access tubes were taken in 2013 0r 2014. Since the soil was dry, it can be concluded the there is no leaching of water or nutrients through the soil profile to deeper layers.

The choice of fertigation technique (continuous vs pulsed, and drip vs microsprinkler) had no significant effect on tree productivity in any year (**Figures 7, 8, 9)**. Since the adoption of continuous fertigation strategy has a high potential to reduce nitrate losses that can be caused by the short term over application of N that occurs in traditional split

N application (2-4 splits), these results suggest that the adoption of a continuous N fertigation approach will be of benefit to the industry.

Table 1. Treatment description for Experiment 2: Nitrogen Fertigation experiment.

F300-0	No K, 300 lbs N as UAN in 4 in season fertigations 20% Feb, 30% April, 30% June, 20% post-harvest.
F300-75KTS 125 SOP	200 lb K. 125 lb K as SOP band February, 75 lb as KTS and 300 lb N as UAN in 4 in season fertigations 20% Feb, 30% April, 30% June, 20% post-harvest (Grower Standard).
F300-75KN-125 SOP	200 lb K. 125 lb K as SOP band February, 75 lb as KNO3 and 273 lb N as UAN in 4 in season fertigations 20% Feb, 30% April, 30% June, 20% post-harvest.
C300-200SOP	200 lb K as SOP dissolved in gypsum mixer and 300 lbs N as UAN (total N 300), continuous application.
C300-75KN	200 lb K. 125 lb K as SOP in band February, plus 75 lb K as KNO3 and 273 lb UAN continuous.
C300-200KN	200 lb K as KNO3 and 193 lbs N as UAN (total N 300) as continuous application.
C300-300KN	300 lb K as KNO3 and 128 lbs N as UAN (total N 300) continuous.
C300-150 KCl 150 KNO3	150 lb K as KCL, 150 lb K as KNO3, 248 lbs N as UAN continuous fertigation.

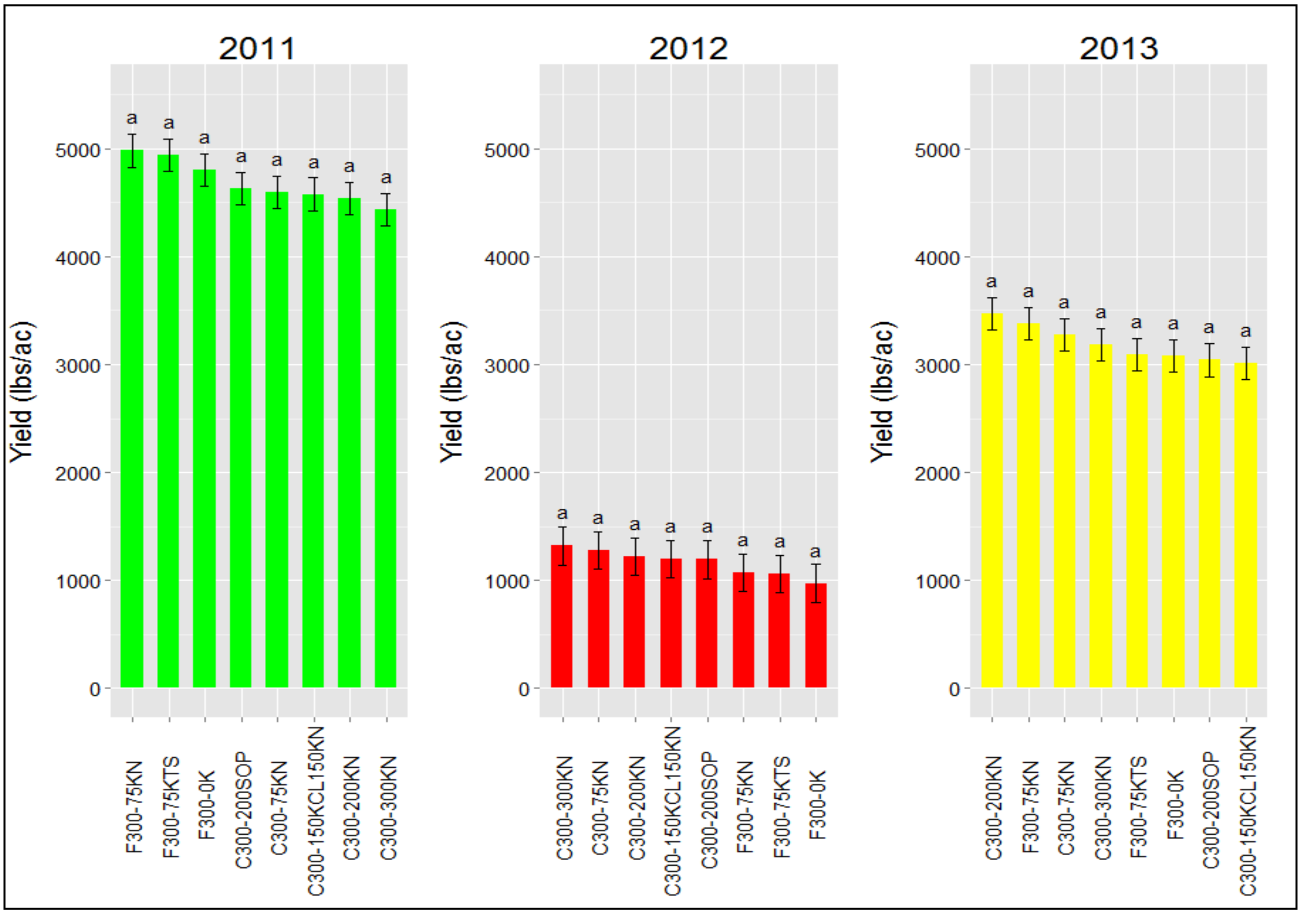

Figure 7. Effect of fertigation practices on almond yield.

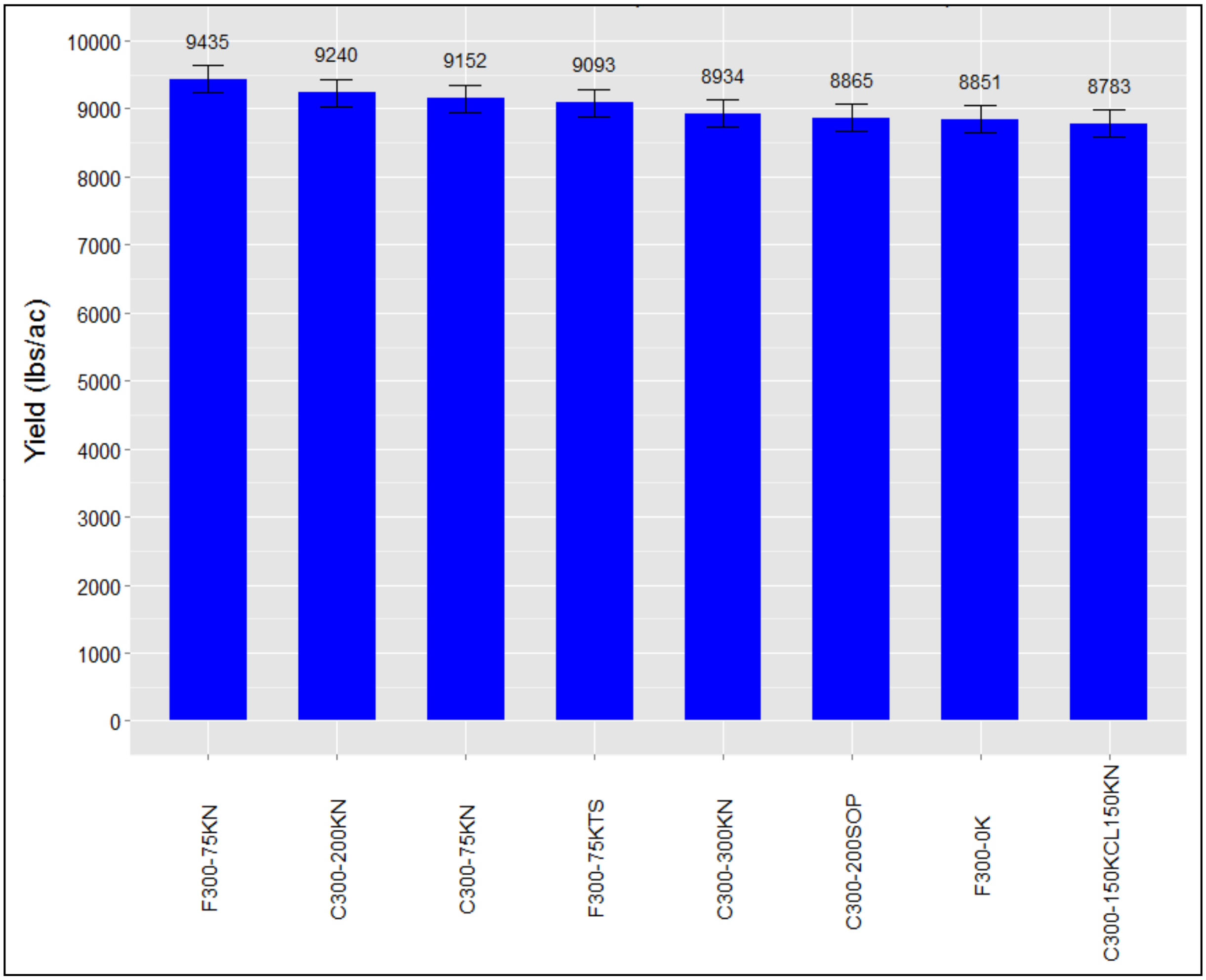

Figure 8. Effect of fertigation practices on cumulative almond yield.

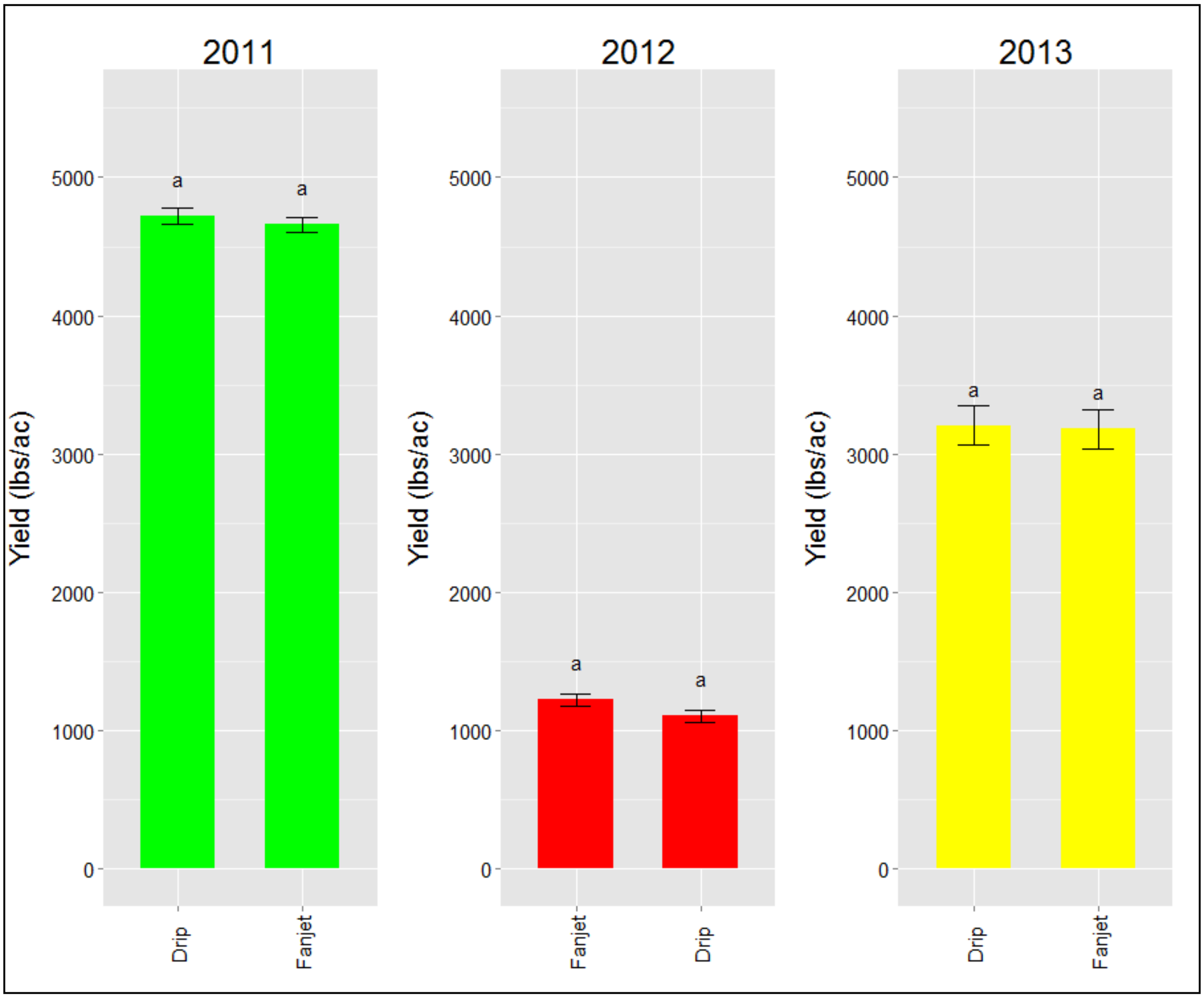

Figure 9. Effect of irrigation practices on cumulative almond yield.

The direct measurement of root growth parameters conducted here has provided the best analysis to date to determine when in the season root growth occurs in almond. Since the acquisition of water and nutrients are the main root functions it is important to understand the physiology and dynamics of roots. Root growth primarily occurs in spring (Mid-March – early June) coincident with leaf expansion and early fruit development. A much smaller flush of roots also occurs in the postharvest period prior to leaf fall. Nitrogen rate or irrigation method has no effect on root growth patterns. Irrigation method or N rate had no effect on root growth, however current year yield has a very strong effect on root growth with increasing yield resulting in reduced root growth. The majority of all root growth is within the surface 60 cm of the soil.

The results obtained from this project can provide valuable information to increase water and water use efficiencies, by applying them at the right time and the right place. The knowledge of root behavior and the interaction with aboveground processes plays a key role in the determination of best management practices.