Potassium Fertilizer Application in Drip and Micro-Jet Irrigated Almonds

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Keywords: almond, yields, potassium, leaf potassium concentration

Abstract

Potassium fertilizer recommendations for California almond [*Prunus dulcis* (Mill.) D.A. Webb] production were developed decades ago for flood and sprinkler irrigated full-coverage orchard conditions. High rates, up to 930 kg K ha^{-1}, at considerable expense were often suggested on soils exhibiting high levels of K fixation. Today, almonds are widely produced under low volume irrigation, which greatly limits the wetted soil area and restricts almond root systems to a relatively small portion of total soil volume. A field trial was conducted comparing fall applied surface banded potassium sulfate (BKS) with in season injected potassium sources: sulfate (KS), thiosulfate (KTS) and mono-potassium phosphate (MKP) through three irrigation systems: single line drip (SLD), dual drip (DD) and micro-jet (MJ) on two almond cultivars, 'Nonpareil' and 'Butte' at the Nickels Soil Laboratory. Yields for the SLD and DD were nearly the same in 1997 and 1998 but somewhat lower than the MJ. In 1999, the DD had the highest yield followed by the MJ and then the SLD. Three year average yields were 3111, 2990 and 2832 kg ha^{-1} for the MJ, DD and SLD systems, respectively. The Butte cultivar had significantly higher yields in 1997 and 1998 as well as the 3 year average yield of nearly 400 kg ha^{-1} higher than the NonPareil cultivar. The 1999 yields showed a strong trend for response to applied potassium with some significant differences over the control and between fertilizer sources and placement. The highest yield was recorded with 1.13 kg K tree^{-1} MKP, then by 2.26 kg K tree^{-1} from banded KS and injected KS, followed closely by the 1.13 kg K tree^{-1} of injected KS and KTS with the control yielding 800 kg ha^{-1} less than the highest yielding MKP. Leaf total K increased significantly with applied K over the three year study with MJ showing the greatest increase followed by DD and then SLD system.

INTRODUCTION

The irrigation of almonds is accomplished with a number of different systems that may apply the necessary water to a very limited soil volume up to flooding the entire soil surface and wetting all of the soil. High yielding almond orchards with declining leaf potassium levels on the West side of the Sacramento Valley and other areas of the state have given growers cause for concern regarding how best to apply potassium. The 1996 Almond Production Manual (Brown and Uriu, 1996) suggests 9.08 kg K_2SO_4 tree^{-1} is desirable for a multiple year quantity to adequately supply the potassium nutrition needs of the orchard. As orchards often have planted densities of 150 to > 300 trees ha^{-1} this resulted in considerable expense, or, if potassium chloride were applied at these high rates, chloride toxicities may result. Fertilizers are applied to the soil surface in a band or broadcast before irrigation or winter rains, or through the irrigation system. In this way the fertilizer is placed in the wetted soil where tree roots will come in contact with the potassium. If added through a low volume or smaller wetted area system, even potassium fertilizers, which are not easily moved in soils, have been taken up readily by trees (Uriu et al., 1980; Andreu et al., 1997). Some fertilizers, however, are not dissolved easily or water quality characteristics prohibit trouble free injection into irrigation systems. Growers choose to apply potassium fertilizers on the soil surface in a band approximately

1.2 m from the tree row as an alternative. The availability of several new formulations of potassium: as sulfate, phosphate and thiosulfate make it easier to inject into irrigation systems. Potassium chloride is the most economical source of potassium but the addition of chloride represents a potential detrimental effect. Given the different types of application now being utilized, it seems prudent to evaluate the relative efficiency of potassium uptake from several sources and methods of placement under three of the more typical low-volume irrigation systems (Schwankl et al., 1999).

The objectives of this study were: 1) to evaluate three irrigation systems: micro-jet (MJ), single (SLD) and dual line drip (DD) as they influence the response of potassium fertilizers on the nutrient concentrations in leaves and nut meat yields of almonds; and 2) to evaluate the effects of fall banded potassium sulfate (BKS) versus in-season injected potassium thiosulfate (KTS), mono-potassium phosphate (MKP) and several rates of potassium sulfate (KS) on the nutrient concentrations in leaves and nut meat yields of almonds.

MATERIALS AND METHODS

The Butte and NonPareil cultivars of almond [*Prunus dulcis* (Mill.) D.A. Webb] of the irrigation system comparison trial on the Marine Avenue location of Nickels Soil Laboratory, Arbuckle, California were selected for this study. The orchard was planted in the spring of 1990 to 4 cultivars: Butte (B), NonPareil (N), Carmel (C), and Monterey (M) in a B-N-C-B-N-M sequence but only the first two rows of Butte and NonPareil were utilized in this experiment. The soil at the site was an Arbuckle gravelly loam (Fine-loamy, mixed, thermic Typic Haploxeralf) having the characteristics given in Tables 1 and 2. Even though the soil exchangeable-K levels are in the adequate range (> 100 mg kg^{-1}), the clay content is rather low and after 5-10 years of high yield production, leaf K concentration often drop below 10 g kg^{-1} indicating a potassium response can be expected. Each individual plot size was 5 trees with a 4.9 m in-row spacing and 6.7 m between rows in a “diamond” arrangement (307 trees ha^{-1}). There was a total of 36 individual plots; three irrigation systems by six fertilizer treatments by two almond cultivars, each having 5 trees in this experiment. The two cultivars: NonPareil and Butte served as two replications for the irrigation and fertilizer treatments. The six treatments applied annually were: Control (no K), 0.38 kg K $tree^{-1}$ as KS, 0.75 kg K $tree^{-1}$ as KS, 0.38 kg K $tree^{-1}$ as MKP, 0.38 kg K $tree^{-1}$ as KTS, and 0.75 kg K $tree^{-1}$ as BKS. Each treatment was randomly assigned within the three irrigation systems and two cultivars. Liquid KS was injected as Great Salt Lake ESP™ (1-0-8), KTS was injected as liquid 0-0-25, and MKP was a dry granular material (0-52-34) added to water to inject as a liquid. Liquid fertilizer injection units were designed, built and installed the summer of 1996 to inject fertilizer for each 5 tree plot. The two main irrigation systems, one for the drip (both SLD and DD) and one for the MJ, were turned on approximately one hour before any fertilizer was injected to improve the uniformity of application. Dry granular potassium sulfate (0-0-50) was applied on the soil surface in a band 7-10 cm wide approximately 1.22 m from the tree on both sides of the tree row. The trial was initiated with the band applications being made the fall of 1995, which is the normal grower practice. Liquid materials were injected through cylinders for each individual plot of 5 trees which were 15 cm in diameter and various lengths (60 up to 150 cm) to accommodate the different volumes of liquid fertilizer having a range in potassium concentration. Potassium fertilizer injection treatments were applied in July and August of 1996 (both after leaf sampling); May and June of 1997 (both before leaf sampling); and June and July of 1998 and 1999 (first before and the second after leaf sampling) with the 0.75 kg K $tree^{-1}$ injected rates being split into 2 applications.

Leaf samples (25 leaves from each of the 5 trees per plot) were taken three times each year and analyzed for Total N, P, K, S, Zn, Mn, B, and Cl to evaluate the nutrient status. Leaf samples were taken on April 4, July 7, and October 7, 1997; April 2, July 7, and October 8, 1998; as well as March 31, June 29, and October 13, 1999 to evaluate nutrient concentrations. Yield data were collected on August 27, (NonPareil) and

September 23, 1997 (Butte); September 22, (NonPareil) and October 9, 1998 (Butte) as well as September 20, (NonPareil) and October 4, 1999 (Butte) to determine treatment effects. Four to five kg samples were taken from each plot for moisture and meat shellout percentage determination. The 1996 data represent the transition year meat yields since potential kernel numbers are usually determined approximately one year before harvest and our interest was in giving all potassium treatments the opportunity to have nearly equal effect upon tree growth and yield (Table 3 and 4).

RESULTS AND DISCUSSION

The transition year 1996 yields (Table 3) continued to indicate the trend for the MJ irrigation system to result in the highest yields as reported by Schwankl et al. (1999) in the larger plot trial study during the 1994-1996 period. Yields for the SLD and DD were nearly the same in 1997 and 1998 but somewhat lower than the MJ (statistically significant in 1998). In 1999, the DD had the highest yield followed by the MJ and then the SLD. The SLD had a significantly lower yield than did the DD (Table 3). Little information can be offered as to why the DD attained the highest yield in 1999 as compared to previous years when it had somewhat lower yields than the MJ system. The somewhat higher yields over the long term are still evident when looking at the three year average yields of 3111, 2990 and 2832 kg ha^{-1} for the MJ, DD and SLD systems, respectively.

The transition 1996 yields (Table 3) indicate the NonPareil cultivar had a significantly higher yield than the Butte cultivar. However, the Butte cultivar had significantly higher yields in 1997 and 1998 as well as the 3 year average yield of nearly 400 kg ha^{-1} higher than the NonPareil. Week to week changes in wet and cold temperature conditions in the early spring result in considerable variation in pollination, thus the year to year yield fluctuation in cultivars.

The fairly similar pretreatment fertilizer yields in 1996 (Table 3) confirm the random assignment of the six treatments. Although yields were not significantly different for the fertilizer treatments during 1997 or 1998, there did seem to be a trend for increased yield as the rate of applied K increased in 1997 but not in 1998. The 1999 yields indicated a significant increase due to the application of potassium with the greatest increase from MKP. Although yields were not significantly different for the fertilizer treatments for the three irrigation systems during 1997 or 1998, there did seem to be a trend for both the MJ and SLD to show a trend for increased yield as the rate of applied K increased (Table 4). The DD yields did not show this trend, however, a closer review of the 1998 yield data indicates little or no response to any fertilizer treatments for the SLD or the DD but does show a trend for the 0.38 kg K $tree^{-1}$ rate of the KS, MKP and KTS under the MJ system to have slightly higher yields.

Fertilizer treatment effects on yield across the three irrigation systems did not become significant until the 1999 season when the 0.38 kg K $tree^{-1}$ rate of MKP resulted in the highest yield (3727 kg ha^{-1}) (Table 3). This was followed by the two higher rate treatments of 0.75 kg K $tree^{-1}$ as BKS and KS, then the lower rate of KS, the KTS and the lowest yielding control (2904 kg ha^{-1}). It is interesting to note that the 0.38 kg K $tree^{-1}$ rate of MKP gave the highest yield under each of the three irrigation systems (Table 4). It might be suggested that the addition of phosphorus along with potassium could have some role in achieving this greater yield. This is possible since the deficiency and responsive range of leaf phosphorus concentration is not well documented in almond. However, leaf levels of phosphorus were generally in or above the proposed adequate range of 1-3 g kg^{-1} and soil Olsen bicarbonate-P levels were well above the 5 mg kg^{-1} deficiency level used for many crops in California (Table 2). The fertilizer treatment yields for each of the three irrigation systems are given in Table 4. The significant differences indicated in the 1996 pretreatment yields reflect more the significant differences between the three irrigation systems and the two cultivars. The significant differences indicated in the 1999 yields reflect primarily the difference among K sources, rates, placements and irrigation systems. Calculating the response to applied K from the yields given in Table 3, the five fertilizer treatment three-year average response over the control was 265 kg ha^{-1}. The three 0.38 kg K $tree^{-1}$ rate treatment three-year average response was 277 kg ha^{-1} greater than the control while the two 0.75 kg K $tree^{-1}$ rate treatment three-year average response showed only 247 kg ha^{-1}.

Almond leaf potassium concentration response to applied potassium is illustrated in Figure 1. The MJ system showed the greatest increase in leaf K as the rate of application increased in each year of the study. It also had the highest leaf K concentration of the three irrigation systems. The lowest leaf K concentration was recorded with the SLD system in all three years while the DD system was generally intermediate between the MJ and the SLD. The SLD system had the lowest leaf K concentration for the control treatment and the lowest leaf K for the fall banded treatment during the first two years because the drip line was approximately one meter away from the fertilizer band. Only winter rains provided for the wetting of soil and uptake of potassium from the fall banded potassium. The control of the DD system had equal to or the highest leaf K of the three irrigation systems for the three-year study. In 1997, the two cultivars had nearly the same leaf K concentration of 14.5 g kg^{-1} while the NonPareil had greater concentration in both 1998 and 1999 (Data not shown). The 0.75 kg K $tree^{-1}$ injected potassium sulfate treatment had the highest leaf K concentration all three years of the study followed by the banded 0.75 kg K $tree^{-1}$ potassium sulfate treatment. The 0.38 kg K $tree^{-1}$ rate of KTS, KS and MKP was nearly the same and only slightly lower than the higher rate treatments but considerably higher than the control which was approximately 12.0 g kg^{-1}. The control treatments for the SLD were just above the deficiency concentration of 10 g kg^{-1} (10.5, 11.2 and 10.8 g kg^{-1} in 1997, 1998 and 1999, respectively) whereas the MJ system was in the 12.5–13.8 g kg^{-1} range and the DD system was in the 13.6–14.1 g kg^{-1} range.

Given the yield response for the 0.38 kg K $tree^{-1}$ and 0.75 kg K $tree^{-1}$ rates utilized in this study of 277 and 247 kg ha^{-1}, respectively, it would seem the lower rate should be targeted as the more economical rate of application. Fall applied potassium fertilizer should be applied so that the irrigation system will wet the soil where the material has been applied. In this experiment, the SLD irrigation system did not wet the soil where the fall banded potassium had been applied so the yield response to potassium was delayed until winter rains provided for the uptake of potassium and yield response the third year of application. Even though leaf K concentrations continue to increase beyond 15.0 g kg^{-1} or even higher than 20 g kg^{-1} it is doubtful that economics would support concentrations up to or above 16-17 g kg^{-1} (Zeng et al., 2001).

ACKNOWLEDGEMENTS

Support for this work was provided by the Almond Board of California, Roten-Amfert-Negev Fertilizer Co., Tessenderlo Kerley, Inc. and Nickels Soil Laboratory. The authors extend their appreciation to Stan Cutter, field manager at the Nickels Soil Laboratory for his excellent support and cooperation.

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Tables

Table 1. Soil physical and chemical characteristics of the surface 0-15 cm of the experimental site, Nickels Soil Laboratory.

Sample #	pH	EC[1] (S m^{-1})	Ca	Mg	Na (meq/L)	Cl	HCO_3	Sand	Silt	Clay (g kg^{-1})	Gravel
1	5.6	0.025	0.8	0.6	0.7	0.9	0.6	570	230	80	120
2	6.0	0.023	0.9	0.6	0.3	0.7	0.8	580	190	80	150
3	5.7	0.025	1.0	0.7	0.4	0.9	0.8	580	230	80	110
4	5.8	0.026	1.1	0.8	0.4	0.5	0.8	580	260	80	80

[1]EC=electrical conductivity of saturated paste, Ca, Mg, Na, Cl and HCO_3 are given as concentration in saturated paste extract.

Table 2. Soil organic and nutritional characteristics of the surface 0-15 cm of the experimental site, Nickels Soil Laboratory.

Sample #	Total N (g kg^{-1})	Total C	Olsen-P	Exchangeable-K (mg kg^{-1})	Zn (DTPA)
1	0.7	5.2	14.8	175	7.2
2	0.7	5.6	14.6	197	8.6
3	0.7	5.4	10.1	165	10.2
4	0.8	6.9	6.1	165	8.8

Table 3. Almond meat yields for the three irrigations systems, two cultivars and potassium fertilizer treatments at Nickels Soil Laboratory.

Treatments	Yield (kg ha^{-1}) 1996	1997	1998	1999
Irrigation systems				
Single line drip	2236 b	2688	2698 b	3110 b
Micro-jet	2557 a	2933	3126 a	3274 ab
Dual drip	2082 b	2738	2703 b	3529 a
$LSD_{0.05}$	195.4	NS	306.2	295.5
Cultivars				
NonPareil	2679 a	2479 b	2558 b	3275
Butte	1904 b	3095 a	3126 a	3334
$LSD_{0.05}$	262.8	561.9	264.7	NS
Fertilizer Treatments				
1. Control (no K)	2192	2500	2868	2904 d
2. 0.38 kg K $tree^{-1}$ K_2SO_4	2382	2719	2916	3313 bc
3. 0.75 kg K $tree^{-1}$ K_2SO_4	2305	2797	2792	3335 abc
4. 0.38 kg K $tree^{-1}$ MKP	2251	2862	3067	3727 a
5. 0.38 kg K $tree^{-1}$ KTS	2345	2867	2824	3015 cd
6. 0.75 kg K $tree^{-1}$ band K_2SO_4	2275	2978	2585	3534 ab
$LSD_{0.05}$	NS	NS	NS	398.6

Table 4. Almond meat yields for the potassium fertilizer treatments for each of the three irrigations systems at Nickels Soil Laboratory.

Treatments	Yield ($kg\ ha^{-1}$) 1996	1997	1998	1999
	Single line drip			
1. Control (no K)	2262 bcde	2255	2701	2656 e[1]
2. 0.38 kg K $tree^{-1}$ K_2SO_4	2181 bcde	2890	2856	3283 abcde
3. 0.75 kg K $tree^{-1}$ K_2SO_4	2327 abcd	2373	2740	2900 cde
4. 0.38 kg K $tree^{-1}$ MKP	2171 bcde	2703	2837	3543 abc
5. 0.38 kg K $tree^{-1}$ KTS	2461 abc	2863	2549	3028 bcde
6. 0.75 kg K $tree^{-1}$ band K_2SO_4	2012 de	3046	2509	3249 abcde
	Micro-jet			
1. Control (no K)	2266 bcde	2495	2962	2612 e
2. 0.38 kg K $tree^{-1}$ K_2SO_4	2729 a	2708	3266	3052 bcde
3. 0.75 kg K $tree^{-1}$ K_2SO_4	2589 ab	3185	3022	3420 abcd
4. 0.38 kg K $tree^{-1}$ MKP	2455 abc	3317	3306	3892 a
5. 0.38 kg K $tree^{-1}$ KTS	2713 a	2663	3592	2800 de
6. 0.75 kg K $tree^{-1}$ band K_2SO_4	2589 ab	3233	2604	3871 a
	Dual drip			
1. Control (no K)	2046 cde	2750	2943	3444 abcd
2. 0.38 kg K $tree^{-1}$ K_2SO_4	2237 bcde	2559	2629	3604 abc
3. 0.75 kg K $tree^{-1}$ K_2SO_4	1998 de	2832	2615	3685 ab
4. 0.38 kg K $tree^{-1}$ MKP	2127 cde	2564	3056	3746 ab
5. 0.38 kg K $tree^{-1}$ KTS	1864 e	3074	2328	3218 abcde
6. 0.75 kg K $tree^{-1}$ band K_2SO_4	2222 bcde	2652	2641	3482 abcd
$LSD_{0.05}$	430.2	NS	NS	627.3

[1]Duncan Multiple Range Test

Figures

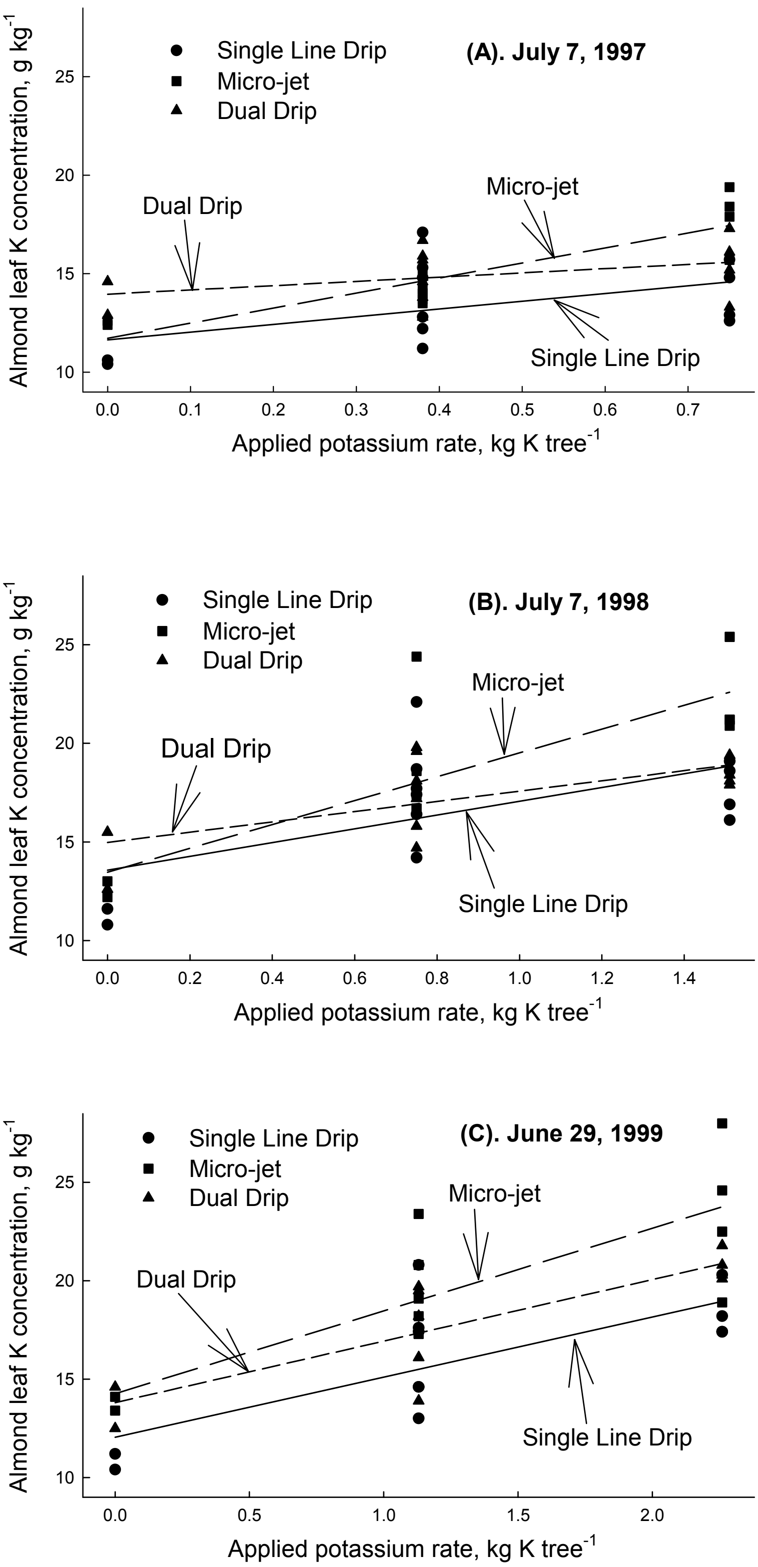

Fig. 1. Almond leaf potassium concentration response to rate of applied K the first (A), second (B) and third (C) year after treatments were initiated.