Effects of Timing Different Organic Matter Amendments on Tree Growth, Nutrient Availability, Food Safety, Soil Moisture and Stem Water Potential

Project Numbers: **15-PREC7-Brown/Khalsa and 15-PREC7A-Brown/Khalsa**

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Objectives:

1) To scale organic matter amendment (OMA) source and timing treatments to the whole tree in a 3rd leaf orchard and to install access tubes for soil moisture monitoring
2) To estimate decomposition rates of OMA, rates of nutrient release and changes in total soil organic carbon (TOC) and total nitrogen (TN)
3) To measure nutrient availability in the top soil (0 – 4 in) including ammonium (NH_4^+), nitrate (NO_3^-), orthophosphate (PO_4^{3-}) and exchangeable potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), iron (Fe^{2+}) and zinc (Zn^{2+}) from OMA source
4) To compare N availability in the active rooting zone (0 – 20 in) between OMA treatments and the control from estimates of net N mineralization and potential N leaching
5) To determine how OMA source and timing treatments affect trunk circumference and leaf nutrient status
6) To demonstrate that OMA treatments can maintain fruit that are free of human pathogens which may jeopardize food safety
7) To measure the effects of the timing of applications of composted manure on soil moisture and stem water potential (SWP)

Interpretive Summary:

Use of chemical fertilizers for nitrogen (N), phosphorus (P), and potassium (K) nutrition results in beneficial outcomes for agronomic performance, but also comes with economic and environmental costs. Organic matter amendments (OMA) offer a viable option to supplement or partially substitute chemical fertilizers. We examined the effects of OMA source and timing treatments. We applied composted manure and green waste compost in either April or October, and measured their effects on tree growth and nutrient status, nutrient availability, food safety, soil moisture and SWP. We scaled our trial to determine the impact of the treatments on the whole tree and installed access tubes that extend 6 ft deep to monitor soil moisture in the soil profile. We integrated nutrient release curves for N availability in the top soil (0 – 4 in), active rooting zone (0 – 20 in) and potential leaching. We also began monitoring trees for changes in trunk circumference, leaf nutrient status, and stem water potential (SWP).

Multiple effects from OMA source and timing treatments were identified in this study. Total organic carbon (TOC) and total nitrogen (TN) significantly increased in the soil (0 – 20 in) from both OMA sources. There was no difference in rate of N release between composted manure and green waste compost. For both materials the N release rate was more rapid in April and progressively slowed during the course of the growing season, which followed an exponential decay. Inorganic N adsorbed to resin stakes in the top soil (0 – 4 in) were not different between the normally fertilized control and OMA treatments, however there were significantly greater P, K, Fe and Zn availability from the OMA treatments. There were no differences between net N mineralization and potential N leaching. These results suggest the N released from OMA is not being lost from the active rooting zone (0 – 20 in) at a rate greater than the control. Soil moisture measured to 6 ft. in depth increased in the composted manure treatment with the greatest effect observed in the October timing. Trees under either OMA treatment had higher SWP compared to control, which is further supported by the positive correlation between SWP potential and soil moisture.

Materials and Methods:

Objective 1) We established a research trial in a 3rd leaf almond orchard outside of Escalon, CA in San Joaquin County. The study site is a Manteca fine sandy loam planted in 2014 with 18' tree and 22' row spacings to varieties of 'Nonpareil' and alternating interplanted rows of 'Aldridge' and 'Carmel'. All trees were grafted on 'Hanson' rootstock. OMA sources from composted manure and green waste compost were compared to the control which is farmed using only chemical fertilizer. The experimental design is a randomized complete split block design with four blocks and three main plot treatments including composted dairy manure (Nunes Dairy Farm Escalon, CA), green waste compost (Recology San Francisco, CA), and the control. There were two timing split plot treatments where each OMA source was applied in either April or October for a total of 20 experimental plots.

Each plot contained 3 subplots of 3 trees randomly selected from a row length of 540 ft. Subplot samples were composited for main or split plot level analysis. Chemical fertilizer was injected in split applications through a microsprinkler system and all plots received the same rate of chemical fertilizer. During March 2016, electrical metallic conduit access tubes of 2 in diameter were installed to 10 ft in depth and 6 ft away from the tree trunk within the zone of microsprinkler coverage. This objective was to apply treatments to whole tree scale.

Objective 2) We utilized a modified “litter bag” technique where composted manure and green waste compost were applied at the equivalent rate of 4 tons per acre on the tree berm to estimate decomposition from OMA. These amendments were contained in a PVC pipe (4 in diameter by 1 in high), attached to coarse-mesh netting (1/32 in openings) and placed on top of the soil. This technique was used to estimate decomposition rates during the study period. As OMA decomposed, samples were collected and processed for analysis of total organic carbon (TOC) and total nitrogen (TN). Net N release was calculated by fitting an exponential decay equation to the total N content found in the remaining OMA mass. In addition to compost analysis, soils from 0 – 4 in and 0 – 20 in deep were sampled, ground, removed of carbonates and analyzed for changes in TOC and TN between the April and October. The objective was to estimate the rate of nutrient release from OMA.

Objective 3) Each month PRS™ probes (Western Ag Innovations Saskatoon, Canada) or resin stakes were deployed for one month at 0 – 4 in. Resin membranes absorbed available nutrients including ammonium (NH_4^+), nitrate (NO_3^-), orthophosphate (PO_4^{3-}) and potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), iron (Fe^{2+}) and zinc (Zn^{2+}). Units are reported in ions cm^{-2} membrane for the duration of the incubation period. Monthly incubations were added up to equal a value for the growing season. This objective was to identify nutrient availability in the top soil between OMA treatments and the control.

Objective 4) At each subplot, thin-walled PVC pipe (6 in diameter and 20 in long) was driven into the soil to a depth of 20 inches in April and October 2015 and again in April 2016. The soil core in the PVC pipe was removed and a nylon-mesh bag containing mixed-bed ion exchange resin beads was secured to the bottom of the core with silicone glue. The soil cores were then returned to the hole. Resin beads adsorb NH_4^+, NO_3^-, PO_4^{3-}, and K^+ but, still allow water to pass freely out of the core (Hart and Firestone, 1989). Potential N leaching was estimated by the amount of inorganic N (NH_4^+ + NO_3^-) adsorbed to resin beads from April to October. Net N mineralization was estimated from changes between initial and final soil inorganic N from April and October within the same soil core. The objective was to identify the net N mineralization and potential N leaching in the active tree rooting zone.

Objective 5) Baseline measurements of trunk circumference from all data trees in subplots were made during January 2016 when the trees were dormant. In July 2016, almond leaf samples were composited across data trees in subplots (Saa et al., 2014). Samples were oven-dried and ground to pass through 60 mesh prior to analysis for total N, P and K.

Objective 6) Samples of OMA that were collected prior to application and fruit samples that will be collected during harvest 2016 will be assessed for the presence of the pathogens including *Salmonella enterica*, *Escherichia coli* O157:H7, and *Listeria monocytogenes* by cultural enrichment followed by immunomagnetic separation and growth on selective media (FDA, 1998). Our objective is to determine if OMA can produce fruits that are free of human pathogens that would jeopardize food safety.

Objective 7) Soil moisture was measured using a CPN 503TDR Hydroprobe at two subplots of timing treatments of composted manure and untreated control, totaling 24 plots. During installation of access tubes, soil samples were taken to determine bulk density at 1ft increments to 6 ft in depth. Hydroprobe counts will be converted to volumetric water content. The probe measures soil moisture within an 8 inch radius, and measurements are taken at 6 inches in depth, then at 1 ft increments until 6 ft. Measurements are conducted at 2 week intervals 1 – 2 days before irrigation events to reflect maximum soil moisture depletion.

Tree water status was evaluated by measuring midday SWP using a Soil Moisture model 3000 pressure chamber on the same trees selected for soil water measurements. A non-transpiring leaf near the trunk was selected and bagged at a minimum of 10 minutes prior to taking the SWP measurement. Readings were taken between 1:00 pm – 3:30 pm and on the same day as soil moisture measurements. The objective was to observe the effect of OMA timing on soil moisture and tree water status.

Results and Discussion:

The research orchard site showed good soil uniformity based on the similarity in TOC and TN in soils (0 – 20 in) between OMA treatments and the control prior to execution of the experiment in April 2015 (**Table 1**). Both composted manure and green waste compost increased TOC and TN demonstrating that the decomposition of OMA results in the movement of organic C and N into the soil. What remains unclear is whether this organic matter remains in an easily decomposable form or has become more stable in the form of soil humus. Multiple studies with OMA in permanent cropping systems have showed an increase in TOC and TN, which led to a more stable soil nutrient reservoir over time (Amiri and Fallahi, 2009; Cayuela et al., 2004; Neilsen et al., 2014; Sanchez et al., 2003).

Decomposition of OMA leads to nutrient release into soil. There were no differences between the rate of nutrient release of N from composted manure and green waste compost (**Figure 1**). After 200 days in the field from April to October 2015, approximately 80% of the N from OMA was released. This process was not linear and instead followed an exponential decay where N was released more rapidly in April and progressively decreased during the course of the growing season. This net N release may be in an organic or inorganic form including particulate organic N or dissolved organic N. Over time this N is converted to inorganic N or retained in organic form. Net N released does not imply all N from OMA is plant available. However, we can infer this N is contributing to the overall TN pool as evidenced by **Table 1**.

The use of PRS^{TM} probes or resin stakes were deployed to measure nutrient availability in the top soil (0 – 4 in). There were no significant differences in inorganic N adsorbed to resin stakes during the 2015 growing season between OMA source, however both treatments were lower than the control (**Table 2**). This result suggests that greater immobilization of soil N occurred with OMA treatments compared to the control. This phenomenon has been reported in annual cropping systems with tilled compost; however, less information is available for permanent crops where OMA is more often applied as mulch (Fortuna et al., 2003). Soil PO_4^{3-} was significantly greater for the composted manure compared to the green waste compost and the control. Exchangeable K^+ for OMA treatments was significantly greater than the control. There were no differences between the OMA treatments and control for Ca^{2+} and Mg^{2+}. However, there were significant differences between green waste compost and the control for Fe^{2+} and Zn^{2+}. In a Georgia pecan study, Wells (2012) reported higher soil P and K and higher leaf Fe and Zn from use of poultry litter compared to a control.

Inorganic N adsorbed to resin stakes in the top soil (0 – 4 in) showed no significant differences between OMA treatments and the control. Along with evidence of net N release from OMA, results might suggest that N from OMA is being lost from the system. However, our measurements of net N mineralization and potential N leaching through the active rooting zone (0 – 20 in) suggest that N released from OMA application is not being lost. There were no significant differences in net N mineralization between OMA treatments and the control. Furthermore, there were no differences in potential N leaching through the active rooting zone (0 – 20 in) between OMA treatments and the control as determined by inorganic N adsorption to resin beads (**Figure 2**). These results further demonstrate that the N released from OMA is retained in the soil as opposed to being lost from the rooting zone through leaching.

Further data from objectives 5 (tree growth and nutrient status) and 6 (food safety) are forthcoming and will be reported at the Almond Conference during December 2016.

Preliminary results indicate greater soil moisture retention under composted manure compared to the control. On average, hydroprobe soil moisture measurements were higher for both April and October applications compared to the control, with the greatest increase observed following the October timing treatment (**Table 3**). The difference in counts between the treatments and control was most apparent at depths of 0 – 24 in; counts were higher by 11% in April and 12% in October compared to the control versus 7.7% in April and 9.8% in October at 0 - 60 in (**Table 4**). Mean SWP measurements were higher for both April and October OMA timing treatments than the control. Spring and summer seasons were analyzed separately and showed similar trends in soil water and SWP. In spring and summer, mean soil water and SWP measurements were higher in the OMA treatments (**Table 3**). As expected, measurements show lower soil moisture and SWP in summer compared to spring, but the decrease is less apparent in the October versus the April OMA timing treatment.

A positive effect on both soil moisture and tree water status of OMA treatments is clear from our initial findings. Soil organic matter improves soil physical properties such as porosity, infiltration, and aggregation, which may increase water holding capacity and retention. We hypothesize that observed differences in soil water are due to improved water infiltration and storage associated with increased soil TOC from decomposition of OMA. In a study by Cook et al. (2006), mulched crop residues increased soil volumetric water content in non-irrigated maize. Walsh et al. (1996) measured greater soil water retention and aggregate stability in apple orchards application with mulched cover crops and OMA. However, no clear effect of mulched compost on soil moisture was observed in a vineyard study (Hannam et al., 2016).

The positive correlation between midday SWP and soil moisture suggests that soil moisture limits tree water uptake. A similar effect was observed by Shackel et al. (1998). Soil moisture and SWP were lower for all OMA treatments in summer, but the smallest decrease occurred in the October OMA timing treatment. Greater soil moisture and tree water status in a high water demand season of summer is potentially due to improved soil quality from the OMA use. It remains to be seen if this trend will continue from late summer until dormancy.

Table 1. Total organic carbon (g C kg^{-1} soil) and total nitrogen (g N kg^{-1} soil) from soils (0 – 20 in) treated with composted manure, green waste compost or as an untreated control. Soils were sampled during April 2015 at the beginning and end of the experiment in October 2015. Values are means (n = 4). Significant ($p < 0.05$) differences between treatments using a Tukey test are reported by different letters within the same column.

	Total organic carbon				Total nitrogen			
	g C kg^{-1} soil				*g N kg^{-1} soil*			
	April		October		April		October	
Control	3.75	a	4.65	b	0.49	a	0.54	b
Composted Manure	3.04	a	5.94	a	0.44	a	0.65	a
Green Waste Compost	3.46	a	5.77	a	0.50	a	0.65	a
p value	0.360		*0.010*		0.790		*0.008*	

Table 2. Total inorganic nitrogen ($NH_4^+ + NO_3^-$), orthophosphate (PO_4^{3-}), exchangeable potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), iron (Fe^{2+}) and zinc (Zn^{2+}) per 10 cm^2 of resin membrane surface from PRS™ probes or resin stakes. Six sets of resin stakes were incubated for a month each in top soil (0 – 4 in) applied with composted manure (Composted M) or green waste compost (GW Compost) compared to a control (Control) during the growing season 2015. Values are means (n = 4). Significant ($p < 0.05$) differences between treatments using a Tukey test and are reported by different letters within the same column.

	NH_4^++NO_3^-		PO_4^{3-}		K^+		Ca^{2+}		Mg^{2+}		Fe^{2+}		Zn^{2+}	
	ug ion 10 cm^{-2} membrane grown season^{-1}													
Control	3647	a	31.56	b	164.8	c	14070	a	3025	a	22.34	b	8.611	b
Composted M	2874	a	123.7	a	1343	a	12850	a	3058	a	23.22	b	14.09	a
GW Compost	3326	a	49.85	b	412.6	b	13240	a	2948	a	38.02	a	16.58	a
p value	0.177		*<0.001*		*<0.001*		0.053		0.581		*<0.001*		*0.001*	

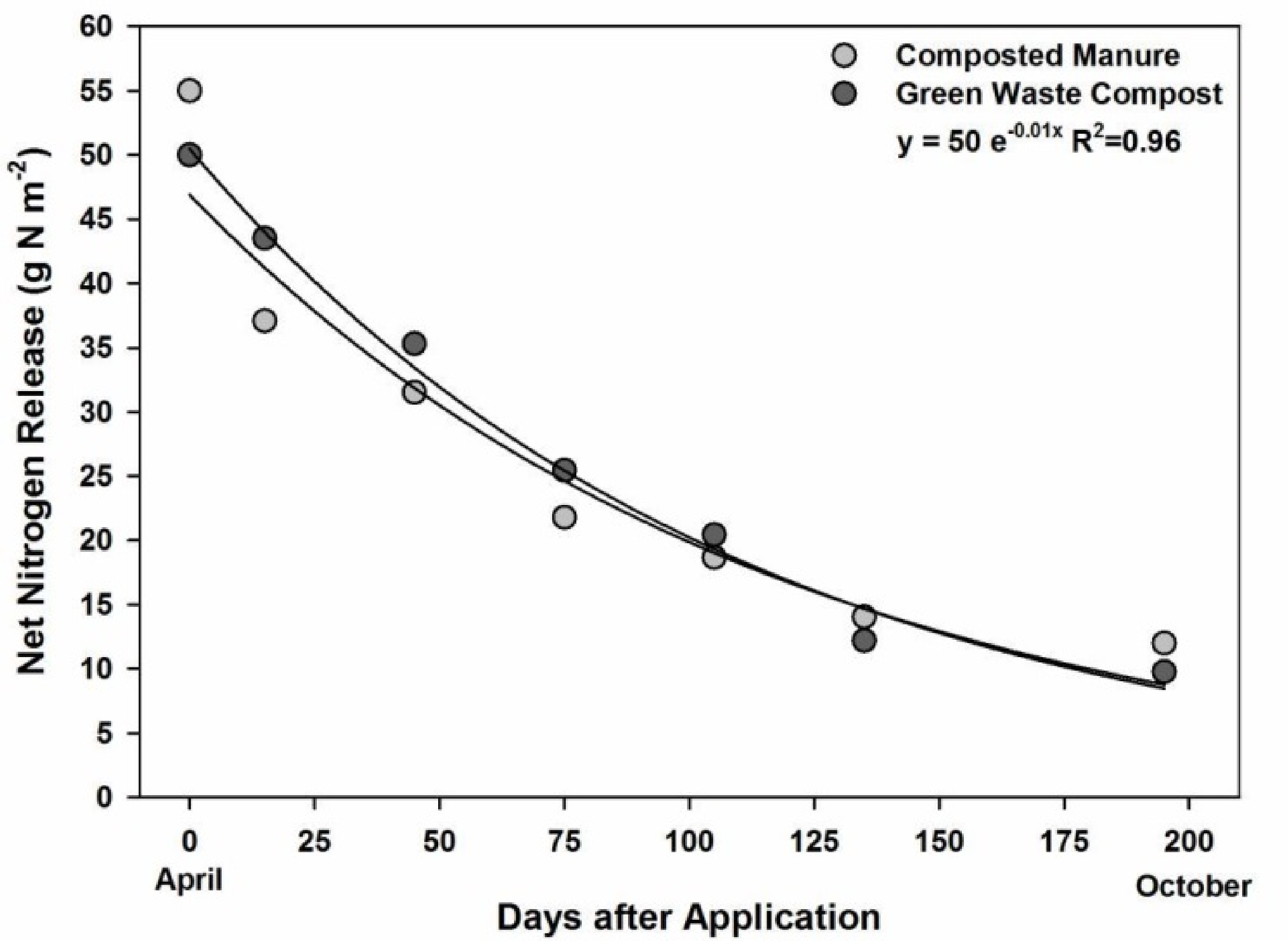

Figure 1. Net nitrogen (N) release represented by mass loss of N from organic matter amendments (g N m^{-2}) from composted manure and green waste compost from day 0 in April to day 200 in October is shown. Values for both organic matter amendments are fit to an exponential decay equation and reported with R^2 for goodness of fit.

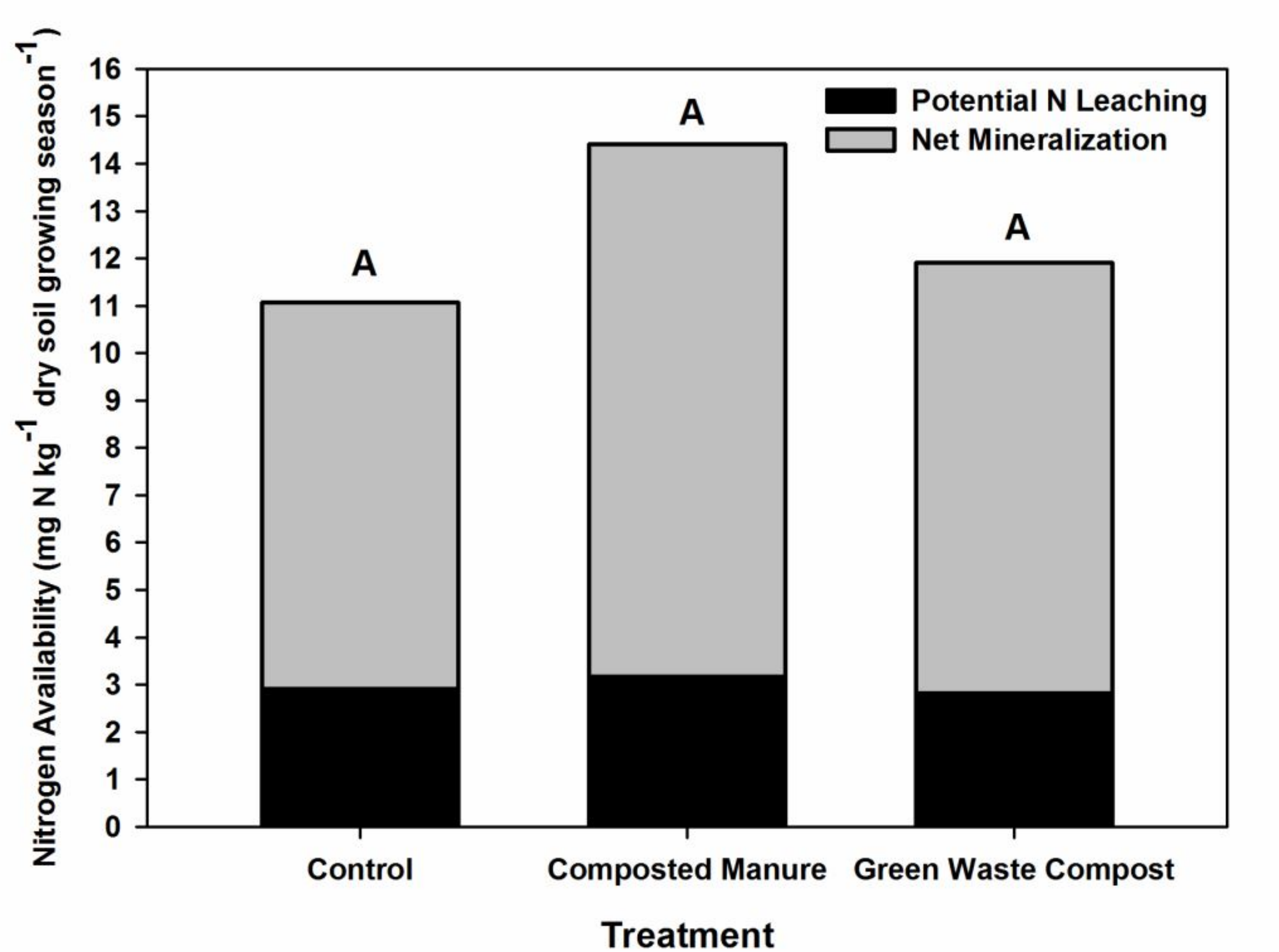

Figure 2. Nitrogen (N) availability (mg N kg^{-1} dry soil growing $season^{-1}$) from composted manure, green waste compost and an untreated control represented by the sum of potential N leaching and net N mineralization is shown. Potential N leaching was estimated by the adsorption of inorganic N (NH_4^+ + NO_3^-) to resin beads (0 – 20 in) attached to the base of a soil core under root exclusion during the growing season from April to October 2015. Net mineralization was estimated by changes in soil inorganic N (NH_4^+ + NO_3^-) within the same soil core (0 – 20 in) from April to October 2015. There were no significant differences between treatments.

Table 3. Soil moisture and stem water potential averages by treatment and season are shown. Treatments are composted manure (Composted M) applied in October 2015 or April 2016. The unit for soil moisture is hydroprobe counts. Stem water potential is in pressure bars. SE is standard error, and CI is confidence interval

Season	Treatment	Mean	SE	95% CI		Mean	SE	95% CI	
		Counts				*Bars*			
Spring	Control	7347	160.8	7028	7665	-9.45	0.40	-8.62	-10.3
	Composted M October	8252	126.9	8000	8503	-9.03	0.36	-8.28	-9.78
	Composted M April	8495	129.4	8239	8751	-8.15	0.44	-7.24	-9.05
Summer	Control	6387	117.1	6156	6618	-15.0	0.49	-14.0	-16.0
	Composted M October	7045	93.88	6860	7230	-13.2	0.48	-12.2	-14.2
	Composted M April	6655	93.17	6471	6839	-13.8	0.53	-12.7	-14.9

Table 4. Soil moisture and stem water potential averages by treatment and depth are shown. Treatments are composted manure (Composted M) in October 2015 or April 2016. The unit for soil moisture is hydroprobe counts. Stem water potential is in pressure bars. SE is standard error, and CI is confidence interval.

Depth	Treatment	Mean	SE	95% CI	
		Counts			
4 – 24 in	Control	6488	98.35	6294	6682
	Composted M October	7309	111.4	7088	7529
	Composted M April	7202	117.1	6970	7433
24 – 60 in	Control	7036	167.6	6705	7367
	Composted M October	7724	120.5	7486	7962
	Composted M April	7576	138.4	7302	7849

Research Effort Recent Publications:

Khalsa S.D.S., Brown P.H. (In Prep) Grower analysis of organic matter amendment use in California almond.

Khalsa S.D.S., Almanza C.A., Brown P.H., Smart D.R. (2016) Leaf litter C and N cycling from a deciduous permanent crop. Soil Science Plant Nutrition. 62:271-276.

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