Stockpile Management to Reduce Aflatoxin Potential

Project No.: **10-AFLA2-Lampinen**

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Objectives:

1. Study the process of stockpiling including examining temperature and moisture conditions in stockpiled almonds in different production areas in California as influenced by different tarp materials.
2. Examine variability in nut drying on the orchard floor as it relates to position in the orchard and midday canopy light interception.
3. Develop recommendations for stockpiling that minimize potential for growth of *Aspergillus* spp. (*A. flavus* and/or *A. parasiticus*) that result in aflatoxin contamination of the crop.

Interpretive Summary:

Different tarp materials covering stockpiles resulted in significant differences in midday high temperatures and day to night temperature fluctuations. This is important since these temperature swings are associated with condensation of water on tarps, which can potentially cause problems for mold growth. The coolest daytime temperatures and smallest day to night temperature swings occurred on stockpiles covered with the white on black tarps (white side facing up). The highest daytime temperatures and greatest day to night temperature fluctuations occurred on stockpiles covered with clear tarps. The amount of visible black mold growth was much less on the stockpile covered with the white on black tarp compared to the clear tarp covered stockpile with the white tarp covered stockpiles having intermediate amounts of mold growth. However, growth of white and green mold occurred under the white on black tarp when the in-hull nuts were stockpiled in a wetter condition. It appears that white on black covered stockpiles could

potentially reduce food safety risk during the stockpiling process in almonds but it is still important to assure that the stockpiled crop is not excessively wet.

Moisture content of in-hull nuts both the wet and dry stockpiles increased over the approximate six month storage period at all locations in the pile including the interior. This is an issue that should be considered in deciding the initial moisture content of stockpiles since ambient humidity conditions can lead to increasing moisture content over the winter storage period.

Moisture content of crop dried directly on the orchard floor after shaking (no windrowing) showed there is a range of about two percent in moisture content at the end of the drying period with the wettest in-hull nuts coming from the north side of the tree near the trunk and the driest from the middle of the drive row. Crop that was windrowed immediately after shaking and then dried in the windrows also showed about a two percent range in moisture content with the driest on the top of the windrow and the wettest at the bottom. Across all orchard floor drying environments, there was about 30-40% variability in the in-hull nut moisture content (as assessed by measuring relative humidity in containers of raw samples from field after equilibrating to constant temperature). This moisture variability is less of an issue when the population of in-hull nuts is in the drier range than those in the wetter range.

Materials and Methods:

<u>Stockpiles</u>
In 2007-2009, the goals of the stockpiling studies were to examine the temperature and moisture conditions in stockpiled almonds in several production areas in California. The ultimate goal is to develop recommendations for stockpiling that minimize potential for growth of *Aspergillus* and resulting aflatoxin. In 2009, different tarp materials were examined including clear, white, and white on black tarps.

In 2010, the main goal of this project was to investigate the impact of different tarp materials (clear and white/black) on stockpile conditions as they relate to aflatoxin potential. Six stockpiles were set up in Kern County. Two stockpiles were taken from an orchard that tends to be harvested somewhat wetter and two piles were taken from an orchard that tends to be harvested drier. The stockpiles were outfitted with temperature and relative humidity sensors at three locations in the stockpile- near the top, on the edge where condensation has been observed and 3 feet down in the center of the pile where conditions are relatively constant.

<u>Crop drying on orchard floor</u>
Because of the problems that can occur when in-hull nuts are stockpiled with excessive moisture, one of the objectives of this project is to develop methods of assessing moisture content before picking up the crop. Using the equilibrium relative humidity above a sealed container of in-hull nuts is one method of estimating moisture content since once the sample equilibrates with the air in the container, the relative humidity above the sample will give a reading of the water activity of the sample. A Rotronics

Hygropalm 1 relative humidity moisture meter (http://www.rotronic-usa.com/shop.htm) was used to measure equilibrium relative humidity above samples of almonds taken from the orchard floor under various scenarios.

We collected extensive orchard floor temperature data with our Mule mounted lightbar in the summer of 2010 (See project 10-HORT13-Lampinen, Development and Testing of a Mobile Platform for Measuring Canopy Light Interception and Water Stress in Almond) and these data were then used to select areas of varying light interception in the orchards to collect in-hull nuts after drying on the orchard floor. The goal was to assess how the variability in midday canopy light interception across the orchard influenced the drying of crop on the orchard floor.

Results and Discussion:

Stockpiles 2007, 2008 and 2009

Results from 2007, 2008 and 2009 suggested that high moisture content of in-hull nuts and varying temperatures resulting from solar heating and cooling lead to uneven moisture distribution in stockpiles. Condensation of moisture against tarps occurs when warm air heated on the south and west sides of the pile cools. For detailed data from stockpile temperature and relative humidity dataloggers for the 2007, 2008 and 2009 seasons, please see the 2007(07-AFLA2-Lampinen), 2008 (08-AFLA2-Lampinen) and 2009 (09-AFLA2-Lampinen) Annual Reports. To briefly summarize the results, temperatures at all locations inside the pile tended to be higher than ambient temperatures.

Temperature at higher positions in the stockpiles tended to be greater and relative humidity lower compared to that in lower positions. Differences in temperature between high and low positions in the piles tended to get less through the storage period. As expected, temperatures in the stockpiles decreased as the season progressed. Since the air in the stockpile is at equilibrium with the kernels and hulls, the water activity in the pile should be equal to the (relative humidity)/100 as shown on the bottom axis of **Figure 1**. These data agree well with published recommendations on almond storage in the UC Almond Production Manual, Page 275 (UC Division of Agriculture and Natural Resources, Publication 3364). The levels of relative humidity in the Kern County stockpiles were well below the 65 – 70% relative humidity recommended in the UC Almond Production Manual (Page 275) to balance the mold growth potential with optimal texture, color, flavor and stability. In contrast the relative humidity in the San Joaquin 1 and 3 piles went above this level and there was *Aspergillus* growth and aflatoxin production. King et al. (1983) found that fungal growth occurred at a water activity greater than 0.75 which is equal to an equilibrium relative humidity greater than 75%.

Of particular note in the 2007/2008 season, stockpiling of in-hull nuts with a water activity notably above the recommended 0.65 - 0.70 (= equilibrium relative humidity of 65 - 70%, see below for explanation) resulted in significant mold growth near the pile surfaces. The two piles where this was observed had initial moisture contents of: 1) hulls 13.1% and kernels 5.2% (total fruit moisture content 9.2%); and 2) hulls 12.0% and kernels 7.3% (total fruit moisture content 9.7%). There was *Aspergillus* growth at the top and bottom edge of these stockpiles and analysis of one pile showed this was associated with aflatoxin production.

Stockpiles 2010

Stockpiles formed from in-hull nuts of differing moisture content in 2010 (**Table 1**) were monitored with temperature and relative humidity probes placed into three locations in each pile as indicated in **Table 1**. Samples were taken from each location at the start of the stockpiling period on 9/18-19/2010 and again when they removed on 2/20/2011. This is much longer than most stockpiles are maintained so it should be considered as a worse case scenario.

Moisture content at all locations in the wet and dry stockpiles as well as under both the clear and white on black tarps increased over the stockpiling period (**Table 1**). This suggests that in-hull nuts that are going to be stockpiled should be brought in with lower moisture content that the final desired moisture. The samples taken from the top and edge of the stockpiles were targeted at specific areas where we have seen problems with visible mold growth in the past. The sensor samples from 3 feet down in the pile (indicated with arrows in **Table 1**) are most representative of conditions for the majority of in-hull nuts in the stockpiles.

Different tarps had significant impacts on temperature profiles. Temperature data from September 2010 from near the top of stockpiles with different types of plastic covering them is shown in is shown in **Figure 5**. Midday high temperatures were greatest and day to night temperature fluctuations were largest for stockpiles that were covered with clear tarps (**Figure 5**). Midday high temperature and day to night temperature fluctuations were lowest for the stockpiles covered with a white on black tarp (**Figure 5**). Visible mold growth (especially black) was greatest on the top and sides of the stockpiles that were covered with the clear tarps and least on the white on black covered stockpile (**Photo 1 and 2**). There was virtually no visible mold growth on the dry stockpile with the white on black tarp (**Photo 1c**).

Photo 1. Photos taken of stockpiles from dry orchard on date of stockpile removal (Mar. 20, 2011). Stockpiles had been in place for approximately 6 months. View of (a) stockpile from orchard harvested under dry conditions that was covered with clear tarp with visible mold growth (left) and white on black tarp with no visible mold growth (right) (b) workers removing in-hull nuts with black mold growth from top of pile under clear tarp, and (c) generally clean in-hull nuts under white on black tarp.

Temperature fluctuations under the clear tarps were always significantly greater compared to the white on black tarps. There were no significant differences in green mold growth (associated with aflatoxin) under the different tarp material at the top or west side of stockpiles (data not shown).

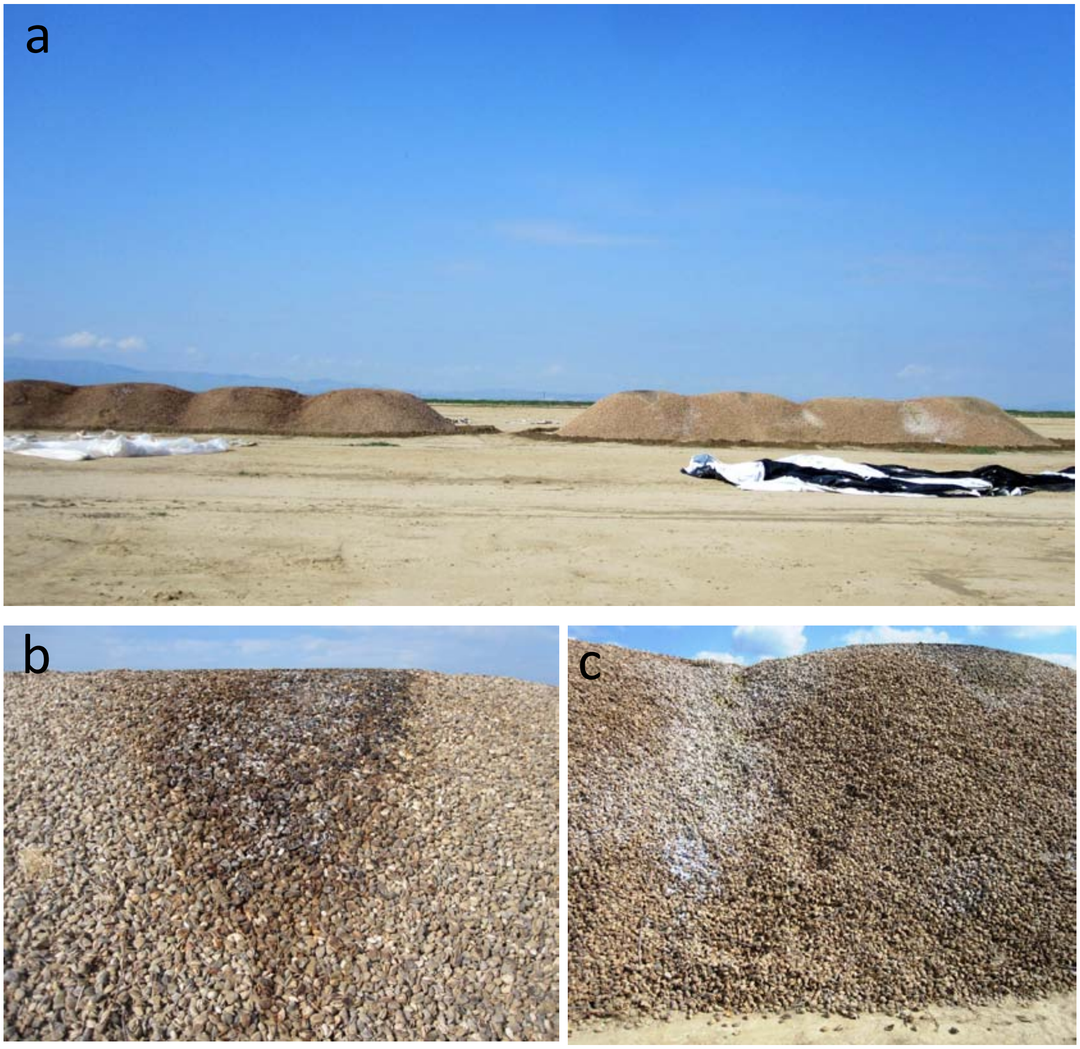

Photo 2. Stockpiles from wet orchard on date of stockpile removal (Mar. 20, 2011). Stockpiles had been in place for approximately 6 months. View of (a) stockpile from orchard harvested under wet conditions that was covered with clear tarp with visible black mold growth (left) and white on black tarp with visible white/green mold growth (right) (b) black and white mold on in-hull nuts from wet pile with clear tarp and (c) white mold growth in valleys under white on black tarp from wet orchard.

The only positive for aflatoxin came the sample from the side of the pile under the clear tarp from the dry orchard (location shown in Photo 1b). No positives for aflatoxin were found from samples from the wet stockpile with either tarp type or from the white on black tarp from the dry orchard stockpiles.

<u>Nut Drying on Orchard Floor</u>

Figure 2 shows data from almonds that were shaken and then swept and windrowed about two days later and then left to dry about 7 days before picking them up. Moisture

content was about 2% higher on in-hull nuts from the bottom of the windrow compared to those from the top (**Figure 2**). This is important since stockpiling at constant, non-excessive moisture content is important to minimize possibility of conditions conducive to fungal growth.

Having a consistent temperature when measuring relative humidity above a nut sample is important. **Figure 3** shows the relationship between temperature and relative humidity in a container with almonds that were put into the container at the field temperature and then brought into a conditioned space for measurement. The in-hull in the container took at least 20 minutes to come to temperature equilibrium with the room and during this time, temperature and relative humidity were changing quite rapidly. It would probably be best if growers took all nut samples into a constant temperature environment such as an air conditioned office for measurement. Samples should be allowed to equilibrate to room temperature before taking humidity measurements. Samples that are densely packed will require more time for equilibration than samples with good air circulation around them.

Moisture content of nut sampled from different positions under the tree indicated about 2% higher moisture near the tree trunk as opposed to in the middle of the drive row in an orchard with about 60% midday canopy light interception (data not shown). Data from this orchard also suggested that as midday canopy light interception increased above 60%, average moisture content of crop drying under the trees increased. These data agree with earlier data collected at our spur dynamics study showing orchard floor temperatures decreased as midday canopy light interception exceeded 60%. This suggests that high canopy light interception/high yielding orchards will require particular care to assure that in-hull nuts are adequately dry before the harvest operation begins. Since an orchard at 60% light interception can potentially produce a yield of about 3000 kernel pounds per acre, it is important that in orchards yielding at or above this level, particular care is given to assure than the crop has adequate time to dry on the orchard floor before pick up.

Although there was some relationship between light interception and yield at some sites, overall the relationship was not particularly strong within any given orchard (**Fig. 4**). Part of the reason for this was the fact that most orchards did not have a great deal of variation in midday canopy light interception.

It is also worth noting that the variability of 30-40% in relative humidity after drying from area of the orchard to another is less of an issue when the samples are on the drier range than the wetter range. For instance, a range of sample relative humidity from 30-50% only results in about a 2-3% range in water content (see **Fig. 1**, middle dashed line for in-hull nuts). However a range from 60-80% results in about a 7-8% range in water content.

Preliminary Conclusions

Moisture content of crop dried directly on the orchard floor after shaking (no windrowing) showed about two percent differences in moisture content at the end of the drying period with the wettest in-hull nuts coming from the north side of the tree near the trunk and the driest from the middle of the drive row. In-hull nuts that were windrowed immediately after shaking and then dried in the windrows also showed about two percent difference in moisture content with the driest in-hull nuts on the top of the windrow and the wettest at the bottom. There was about 30-40% variability in nut moisture content (as assessed by measuring relative humidity in containers of raw samples from field after equilibrating to constant temperature) across the orchard. This is less of an issue when in-hull nuts are in the drier range than in the wetter range.

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Moisture content in both the wet and dry stockpiles increased over the approximate six month storage period at all locations in the pile including the interior. This is an issue that should be considered in deciding the initial moisture content of stockpiles since ambient humidity conditions can lead to increasing moisture content over the winter storage period.

Acknowledgements
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References:

Kader, Adel A. 1996. “In-Plant Storage”, pp. 274-277. In Almond Production Manual, Warren C. Micke, Technical Editor. University of California Division of Agriculture and Natural Resources, Publication 3364.

King, A.D.Jr., W.U. Halbrook, G. Fuller, and L.C. Whitehand. 1983. Almond nutmeat moisture and water activity and it influence on fungal flora and seed composition. J. Food Sci. 48: 615-617.

Table 1. Starting and ending moisture content in dry and wet stockpiles covered with either clear or white on black tarp. Samples taken from location labeled 3' down are from 3' down from the top/center of pile (indicated with arrows) are the most representative of conditions in the overall pile. Samples labeled top and side are taken on outer surface of pile where condensation is most likely. Note that moisture content increased during storage period in all stockpiles at all locations.

Dry stockpile

	Location	Starting % moisture	Ending moisture	Change in % moisture	
clear	Top	4.9	31.6	+26.7	
	3' down	3.7	9.9	+6.2	←
	Side	4.3	6.3	+2.0	
White on black	Top	4.1	9.2	+5.0	
	3' down	5.2	7.2	+2.0	←
	Side	4.7	9.9	+5.2	

Wet stockpile

	Location	Starting % moisture	Ending moisture	Change in moisture	
clear	Top	7.8	27.7	+19.9	
	3' down	8.0	11.5	+3.5	←
	Side	7.5	8.1	+0.6	
White on black	Top	6.2	23.0	+16.8	
	3' down	7.1	10.9	+3.8	←
	Side	6.8	21.0	+14.2	

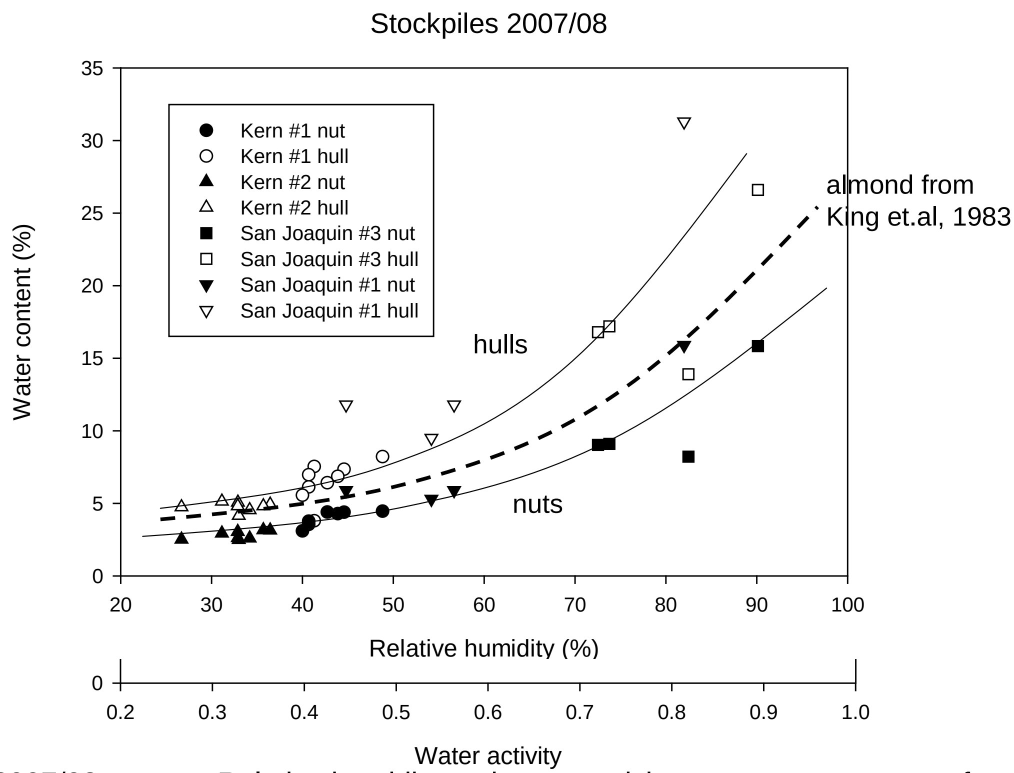
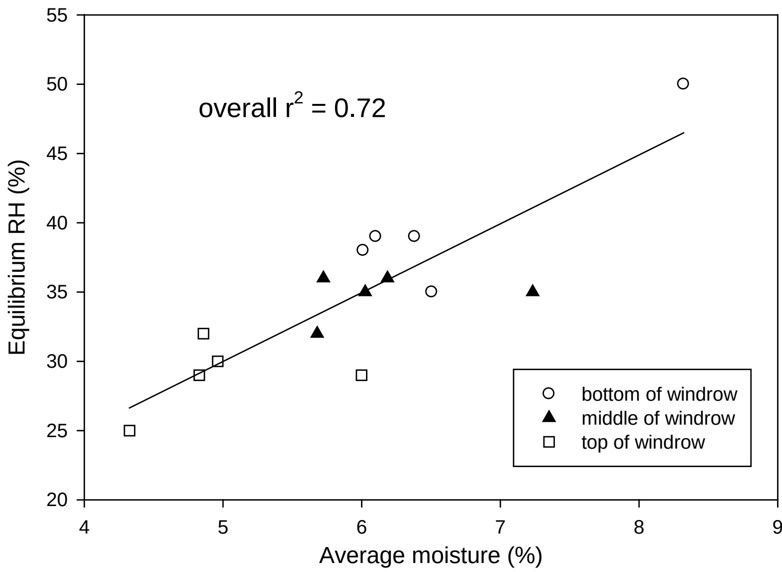


Figure 1. 2007/08 season: Relative humidity and water activity versus water content for nuts (including shell) and hulls from the Kern and San Joaquin County stockpiles. Data include cv. Nonpareil from Kern County as well as stockpile #1 and stockpile #3 from San Joaquin County. Dashed line is the approximate curve for almond kernels from King et. al, 1983.



	sample humidity	sample %moisture
top	29 a	5.0 b
middle	34 b	6.2 a
bottom	40 c	6.7 a

Figure 2. Average moisture content versus equilibrium relative humidity in container of in-hull nuts from three depths in windrows from Colusa County Aldrich orchard. The crop was windrowed about 2 days after shaking and samples were taken 7 days later on date of harvest.

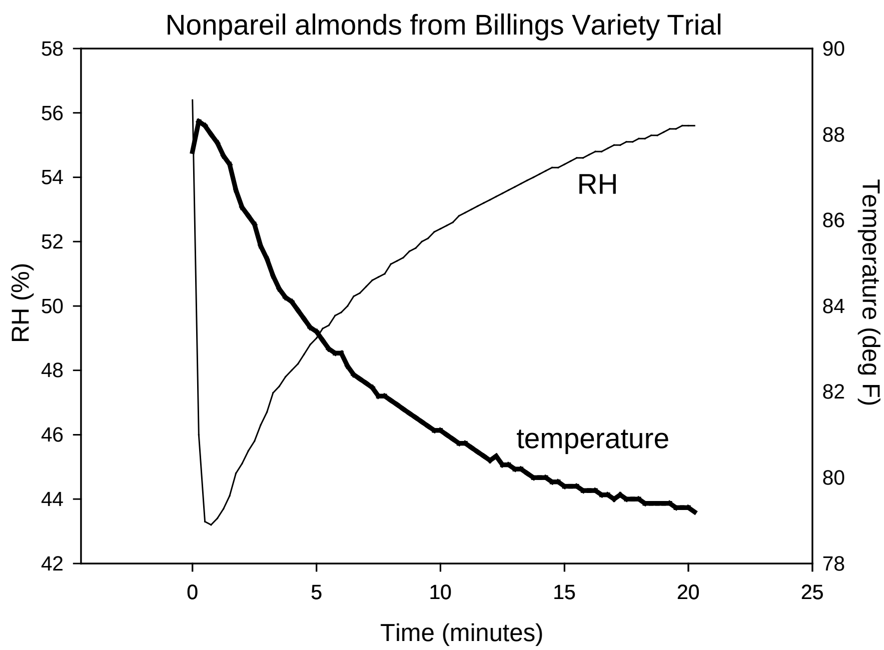


Figure 3. Temperature and relative humidity in container for a period of twenty minutes after enclosing field run samples of in-hull almonds. This figure points out the need to measure moisture content at a constant temperature and not shortly after taking them into a space with a large temperature difference from the sample temperature.

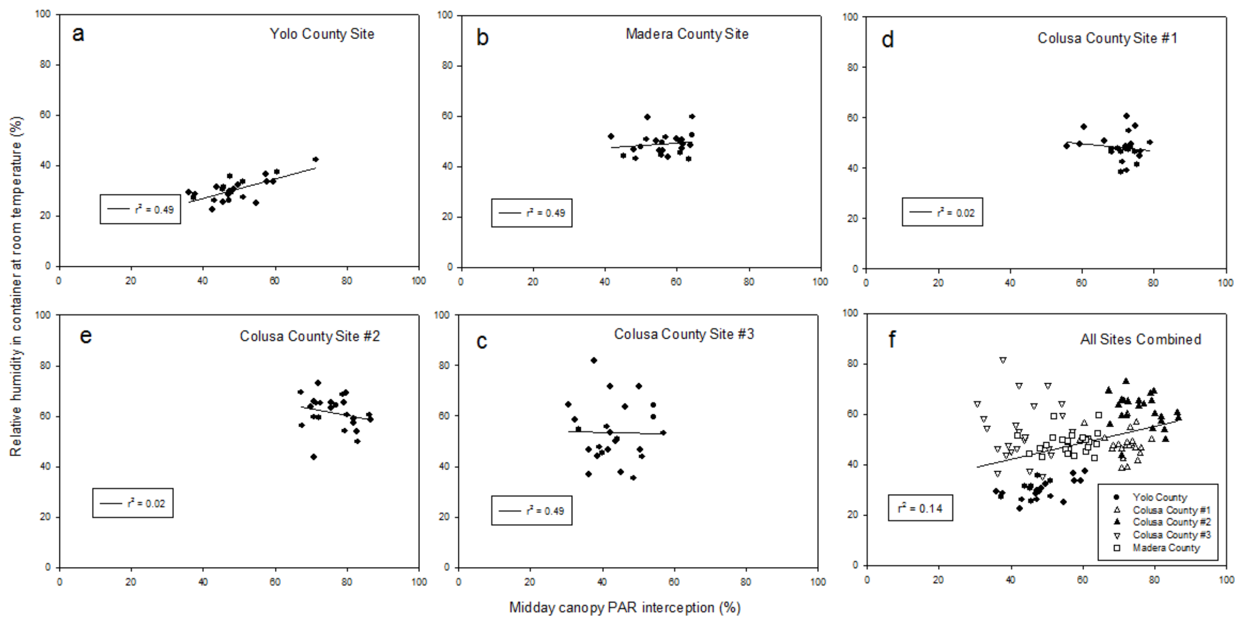


Figure 4. Midday canopy light interception (measured with Mule light bar) and relative humidity in container with nut samples at room temperature. All samples are from Nonpareil rows.

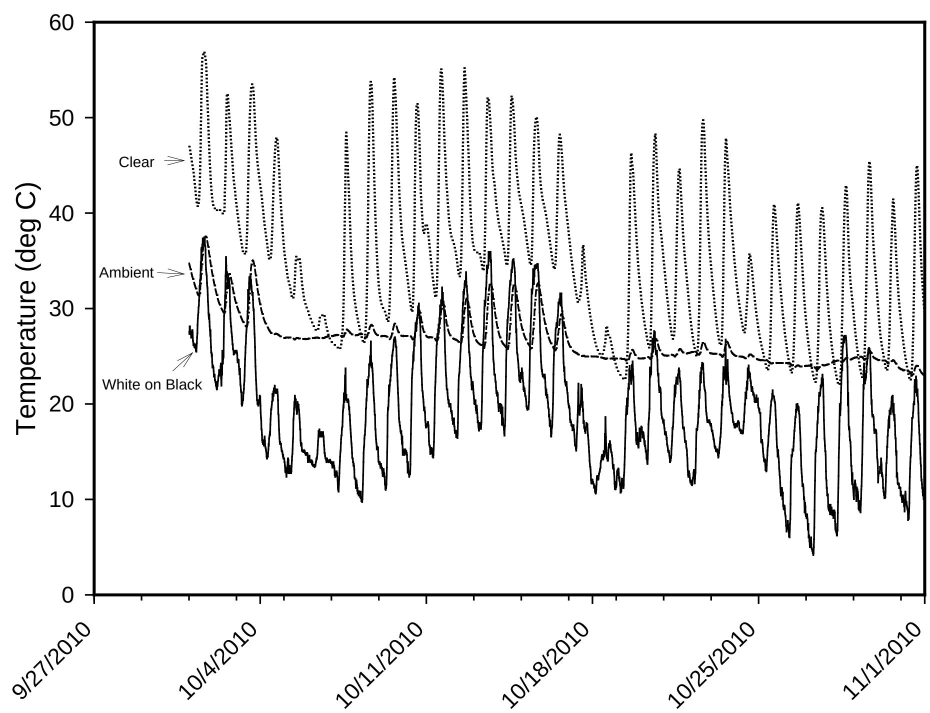


Figure 5. Temperature (in degrees Celsius) near top of dry stockpile under two different types of plastic cover in Kern County in October 2010. High temperatures under different tarp materials of 60, 50 and 40 degrees Celsius correspond to 140, 122, and 104 degrees Fahrenheit.