Harvest and Stockpile Management to Reduce Aflatoxin Potential

Project No.: **12-AFLA2-Lampinen**

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Objectives:

The objectives of this study are to 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. A second objective is to examine variability in nut drying on the orchard floor as it relates to position in the orchard and orchard light conditions. The ultimate goal is to develop recommendations for orchard design/light management and for stockpiling of nuts that minimize potential for growth of *Aspergillus* spp. (*A. flavus* and/or *A. parasiticus*) that result in minimal food safety risk from contamination of nuts.

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 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 stockpiled nuts are not excessively wet.

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.

Moisture content of nuts 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 nuts coming from the north side of the tree near the trunk and the driest from the middle of the drive row. 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 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 nuts are in the drier range than in the wetter range.

Nuts inoculated with a non aflatoxigenic AF36 strain of *Aspergilus* placed in mesh bags in stockpiles under both clear and white on black tarps failed to thrive. When the stockpiles were removed, none of the inoculated strain could be detected suggesting that conditions in these stockpiles were not conducive to *Aspergilus* growth. It should be noted that both of these stockpiles were at the dry end (in hull nuts 6.8 – 7.7% mc) of the spectrum and results might be different if wetter nuts were stockpiled.

A grower can minimize variability in almond drying on the orchard floor by several methods. First, the grower can minimize orchard canopy variability during the orchard development phase by avoiding overirrigation since this will tend to exacerbate the differences between the largest and smallest trees in the orchard since the smaller trees will tend to be too wet and hence be stunted. Second, the grower can plan the orchard such that the maximum level of midday canopy light interception does not exceed 80%. An additional aspect of orchard planning is to orient rows in a north/south direction whenever possible since this allows more even light distribution over the orchard floor through the course of the day and season. This should allow adequate sunlight for drying the nuts on the orchard floor. Third, after shaking, the nuts can be picked up and conditioned to remove leaves and other debris and then redeposited into the center of the drive row where they will receive more even sunlight and hence drying. Fourth, samples can be taken while nuts are on the orchard floor to assure that they are in the desired range of moisture content before nuts are picked up.

Materials and Methods:

Stockpiles

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.

In 2011-12, the work on different tarp types was repeated at the Kern County site. Two stockpiles, each with four mesh bags of inoculated almonds installed in the middle two "humps", one meter down into the nuts were installed. Each inoculated sample had a sensor monitoring the temperature every 15 minutes installed and two samples also had an added temp/rh sensor monitoring every 15 minutes. Batches of Nonpareil almonds were inoculated with an atoxigenic isolate of *Aspergillus flavus (i.e.,* AF36 strain) and placed in mesh bags within the clear and white on black tarp covered stockpiles. This strain does not produce aflatoxin, so that placing the mesh bags in the stockpile will not cause aflatoxin contamination. The almonds were inoculated in the laboratory and incubated so that sporulation of AF36 will cover the almonds. Batches of 20 nuts were enclosed in a plastic mesh bag, attached to a rope and buried at different depths in the stockpile. These treatments were replicated 4 times.

The recovered nets with the nuts were placed in a clean plastic bag in an ice chest, brought to the laboratory and the survival of the strain AF36 determined. If the fungus does not survive that would indicate that the stockpile temperatures kill the *A. flavus*. If it survives we will determine if it survives in all the nuts, or only in some of them. The surviving propagules will be checked to see if they are the AF36 strain (done with VCG=vegetative compatibility grouping tests) or other strains from almond orchards.

Nut drying on orchard floor

Because of the problems that can occur when nuts are stockpiled with excessive moisture, one of the objectives of this project is to develop methods of assessing nut moisture content before picking up the nuts. Using the equilibrium relative humidity above a sealed container of 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 summers of 2010-2012 (see project report for Lampinen et.al 12-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 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 nuts on the orchard floor.

Also in 2011, a diurnal set of measurements were taken using the Mule mounted lightbar in adjacent almond orchards with row orientations running north/south and east west. In both cases, variety composition consisted of 50% Nonpareil, 25% Butte, 12.5% Aldrich and 12.5% Monterey. The orchard was in its fifth leaf and tree spacing was 15' x 24'. Measurements were done with the Mule mounted lightbar at 7am, 8am, 9am, 10am, 11am, 12pm, 1pm, 2pm, 3pm, 4pm, 5pm, 6pm and 7pm. In addition, time lapse cameras were installed in one north/south oriented orchard row and one east/west oriented orchard row. In both cases, the variety on the left of the photos is Aldrich and Nonpareil is on the right.

In 2012, a simulated wetting experiment was conducted in an orchard in Solano County planted in a north/south orientated Butte/Padre orchard on a16'X22' spacing. The experiment was conducted in early May and air temperatures and sun angles at that time were similar to those seen during harvest in an average year. Dried Nonpareil nuts collected from an orchard in Madera County in the previous harvest season were used. Nuts were spread in a single layer covering a 1.5' X 2' rectangle. A steel grid of 4 rectangles was used to layout each rep. Spray paint was used to mark each rep, and a 2 inch space was left between each rectangle to prevent incorrect application to adjacent reps. Five replications containing each of the four water application levels and 2 positions were imposed; 0, 0.25, 0.50 and 0.75 inches of simulated rainfall were applied in both drive row and shaded positions under the tree canopy. Treatments were randomized in a north/south orientation within each replication. A camera (Plant cam http://www.Wingscapes.com) fixed to a tripod was positioned facing north to obtain time lapse photos throughout the day and week to help investigate how the drying patterns relate to sunlight. The sunny position samples were placed in the center of the drive row where the nuts would receive maximum midday sun. The shaded position was placed in a Butte row underneath the canopy approximately 12 inches from the trunk. Nuts were collected in three samples at 2, 24 and 48 hours after the simulated rainfall. 1/3 of the nuts in each rectangle were collected at each sampling and the position sampled within the rectangle during each sampling event was randomized. Water was measured in a graduated cylinder and applied using a plastic garden watering can. Water was applied in 0.25 inch increments across the entire trial until the correct amount was reached for each rep. Samples were placed in zip lock bags and taken to the lab for analysis.

Percent relative humidity (% RH) and temperature measurements were taken with a Rotronic HygroPalm 23 with HC2-C05 miniprobe (http://www.rotronic-usa.com/shop.htm). Fresh weight, % RH and temperature were taken once each sealed sample had reached room temperature in the lab. Kernels were then separated from hull and shell and a weight, % RH and temp was taken for the two portions separately (kernel and hull/shell). Samples were dried at 65 degrees C for 24 hrs. After the samples were dried, weight, % RH and temp were collected for kernels and hull/shell. The two portions were then combined and a total dry weight was taken. Samples were placed in 1500 ml glass canning jars with a 0.53" hole drilled through the lid. The hygropalm probe was inserted through the hole in the lid and a rubber sleeve was fitted around the probe in order to obtain an air tight seal. Since the air in the container should be in equilibrium with the nuts, water activity (W_a) was calculated as the container relative humidity/100.

Results and Discussion:

Stockpiles 2007, 2008 and 2009

Results from 2007, 2008 and 2009 suggested that high moisture content of 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 nuts 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 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 2010-11

Stockpiles formed from in hull nuts of differing moisture content in 2010 were monitored with temperature and relative humidity probes placed into three locations in each pile (**Table 1)**. In hull nut 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 March 2011 from near the top of stockpiles with different types of plastic covering them is shown in is shown in **Figure 2**. Midday high temperatures were greatest and day to night temperature fluctuations were largest for stockpiles that were covered with clear tarps (**Figure 2**). Midday high temperature and day to night temperature fluctuations were lowest for the stockpiles covered with a white on black tarp (**Figure 2**). The dry stockpile covered with the clear tarp had significant visible mold growth while the stockpile covered with the white on black tarp showed no visibile mold growth (**Photo 1**). For the wet stockpiles, visible mold growth (especially black) was greatest on

Photo 1. 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 nuts with black mold growth from top of pile under clear tarp; and (c) generally clean nuts under white on black tarp.

the top and sides of the stockpiles that were covered with the clear tarps and least on the white on black covered stockpile (**Photo 2**). The only positive for aflatoxin came 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.

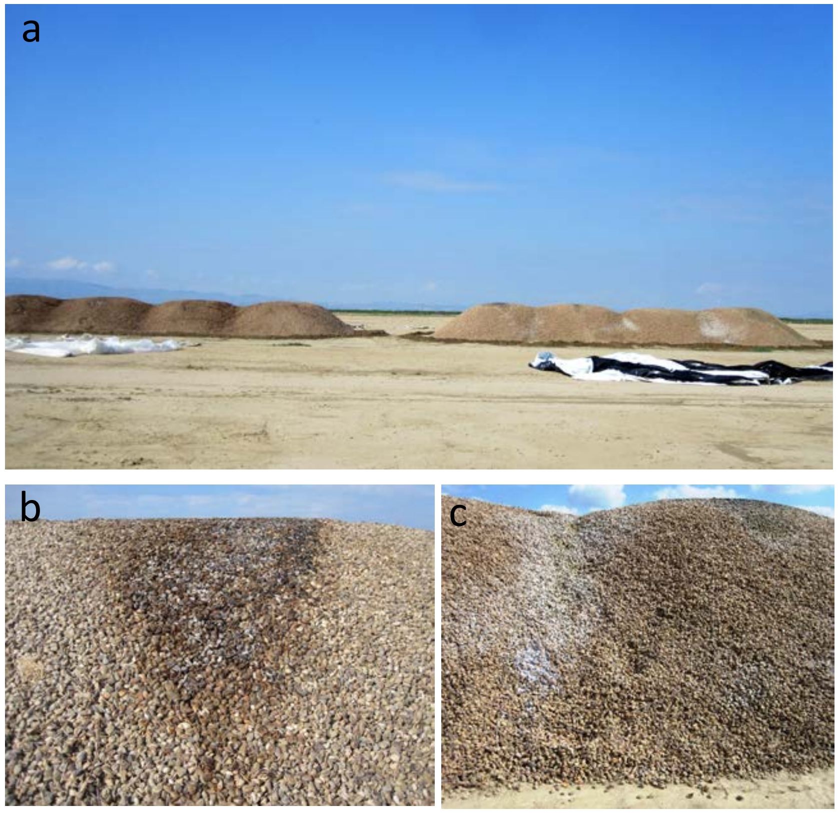

Photo 2. Stockpiles from wet orchard on date of stockpile removal (Mar. 20, 2011). Stockpiles had been in place for approximately 6 months. View of (a) stockpile from orchard harvested under wet conditions that was covered with clear tarp with visible black mold growth (left) and white on black tarp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

<u>Stockpiles 2011-12</u>
Results from 2011-12 stockpiles were very similar to those from previous years for the same tarp types although there was somewhat less visible mold growth in 2011-12, previous years as well as the fact that both stockpiles were relatively dry at initiation. There was virtually no visible mold growth on the white on black tarp covered stockpile in 2011-12.

Temperature fluctuations under the clear tarps were always significantly greater compared to the white on black tarps (**Figure 2**). 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). The larger temperature fluctuations at the top of the clear tarp covered stockpile resulted in a large increase in moisture while the lower position in the the clear tarp covered stockpile and both positions in the white on black covered stockpile showed little change in moisture (**Table 2**).

Inoculation experiment 2011-12

The results are presented in **Table 3**. Samples 1-8 were taken at installation in the first week of December at depth of 1 meter in the piles. **Table 2** contains moisture content information on these piles, which were relatively dry. Samples 9-16 were taken at the time of removal of sensors and inoculated bags in mid-March at 1 meter depth near inoculated bags. Samples 17-24 represent the contents of the bag containing the sensors and the AF36 inoculated samples. The column for mass represents the sub sample that was ground up of which 25 grams was taken for extraction. The inoculated AF36 strain of *Aspergilus* did not appear to be able to survive in the stockpiles under either the clear or white on black tarp under conditions in 2011-12. None of the inoculated bag samples tested positive for the AF36 strain at the end of the trial (**Table 3**). Only one replication in the clear tarp covered stockpile tested positive for aflatoxin and it was at a very low level (**Table 3**).

The relationship between relative humidity (and water activity) for in shell almond kernels plus hulls, hulls, and for in shell kernels is shown in **Table 4**. The green shaded area indicates moisture contents that are acceptable for stockpiling. Red shaded area indicates moisture contents that are too wet. The data in **Table 4** was constructed from a regression across large sample sets from several years of stockpile results. However, it should be noted that the relationship between water content and water activity has been shown to vary depending on how wetting/drying cycles are produced. King et.al (1983) found that at a given water activity, the nut moisture content varied depending on the method of drying. This suggests that the most accurate measurement is water activity since it is directly related to microorganism growth potential.

Nut Drying on Orchard Floor

Figure 3 shows data for 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 nuts from the bottom of the windrow compared to those from the top (**Figure 3**). This is important since stockpiling nuts 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 4** 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 nuts 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 nuts 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 nuts 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 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 nuts have adequate time to dry on the orchard floor before they are picked up.

In general, the higher the canopy cover in an orchard, the wetter the nuts were at the time of harvest in the orchards measured in the current study. **Figure 5** shows the midday canopy light interception versus relative humidity in containers of nuts sampled from the orchard floor at the time of harvest for orchard trials in 2010, 2011 and 2012. These data suggest that growers should not follow a rule of thumb (i.e., leave nuts on orchard floor for 10 days before picking up) but rather do sampling of nuts from the orchard floor before beginning the harvest operation. Drying times should be expected to increase with increasing canopy cover and needs to be taken into consideration.

An example of how the soil surface temperature varies with canopy cover is shown in **Figure 6**. These data are from one day in a Kern County almond orchard. On this 88-93°F day, orchard floor temperature in the middle of the drive row varied from about 40 to 70°C (104 to 158°F). These differences would be expected to result in varied rates of drying of the nuts with high light interception (cooler) areas drying more slowly.

It is also worth noting that the variability of 30-50% in relative humidity after drying from one 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 **Figure 1**, middle dashed line for in-hull nuts). However a range from 60-80% results in about a 7-8% range in water content.

Simulated wetting experiment

Water activity and water content measurements in both the kernel and hull/shell showed similar patterns whether they were dried in the middle of the drive row or under the tree. This is likely because the orchard had relatively low midday canopy light interception. Therefore, data presented here is only for the drive row positions. Significant differences in applied water were observed between the kernel and hull/shell portions with the hull/shell showing notably higher water content compared to kernels. Differences in average water activity were seen between water application levels. A positive correlation was observed between percent moisture and water activity in both positions.

This correlation was more pronounced for the hull/shell portion. Results for the hull/shell were comparable to the findings of King et al. (1983), however water activity values did not exceed the 0.75 level where mold started to develop in their study. The kernel portion showed a lower range in percent moisture compared to the results of the King et al. 1983 study. Our previous data showed a 2 percent difference in water content within a windrow which suggests that more of an effect in the nutmeat portion may have been seen if they had been windrowed instead of left in a single layer.

Figure 7 shows the water activity over the course of the study for the kernels (upper left), and hulls (upper right). The patterns for kernels versus hulls is quite similar with the hulls wetting slightly more due to the water being applied to simulate rainfall being more likely to contact hulls. The lower left figure shows the kernel moisture content over the course of the study and the lower right figure shows the hull moisture content. These two figures look quite different since at a given water activity, kernels and hulls are at quite different water contents. These data suggest that wetting of hulls and kernels as a result of a rainfall event are likely to not be significantly different. This is important since if hulls were wet to significantly higher levels than kernels, food safety risk for stockpiled nuts would be increased.

Conclusions:

Moisture content of nuts 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 nuts coming from the north side of the tree near the trunk and the driest from the middle of the drive row. Nuts that was windrowed immediately after shaking and then dried in the windrows also showed about two percent difference in moisture content with the driest 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 nuts are in the drier range than in the wetter range.

Different tarp materials 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 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 stockpiled nuts are not excessively wet.

The fact that wetting of hulls and kernels as a result of a simulated rainfall event were similar suggest that measurements of overall nut plus hull water activity or moisture content should be a reliable predictor for food safety risk. This is important since if hulls were wet to significantly higher levels than kernels, food safety risk for stockpiled nuts would be increased.

The nontoxigenic strain of Aspergilus did not appear to be able to survive under the stockpile conditions under either the clear or the white on black tarps. It should be noted that nuts in these piles were in an acceptably dry range and results would not necessarily be the same different moisture regimes.

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. This suggests that moisture content of nuts to be stockpiled may need to be lower than the final desired level.

A grower can minimize variability in almond drying on the orchard floor by several methods. First, the grower can minimize orchard canopy variability during the orchard development phase by avoiding overirrigation since this will tend to exacerbate the differences between the largest and smallest trees in the orchard since the smaller trees will tend to be too wet and hence be stunted. The more uniform canopy that is developed, the more uniform nuts will dry on the orchard floor. Second, the grower can plan the orchard such that the maximum level of midday canopy light interception does not exceed 80%. An additional aspect of orchard planning is to orient rows in a north/south direction whenever possible since this allows more even light distribution over the orchard floor through the course of the day and season. This should allow adequate sunlight for drying the nuts on the orchard floor. Third, after shaking, the nuts can be picked up and conditioned to remove leaves and other debris and then redeposited into the center of the drive row where they will receive more even sunlight and hence drying. Fourth, samples can be taken before nuts are picked up to assure that they are in the desired range of moisture content.

Acknowledgements:

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References:

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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.

Tables and Figures

Table 1. Starting and ending moisture content for in hull nuts from dry and wet stockpiles covered with either clear or white on black tarp in 2010-11. 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	

Table 2. Starting and ending moisture content for in hull nuts from stockpiles covered with either clear or white on black tarp in 2011-12. Samples taken from location labeled 3' down are from 3' down from the top/center of pile (indicated with arrows) and those labeled top are from the outer surface at the top of the pile.

	Location	Starting % moisture	Ending moisture	Change in % moisture	
clear	Top	7.2	22.4	+15.2	
	3' down	7.2	7.7	+0.5	←
White on black	Top	6.8	9.1	+2.3	
	3' down	6.8	5.6	-1.2	←

Table 3. Results from inoculation studies with atoxigenic isolate of *Aspergillus flavus (i.e.*AF36 strain). The inoculated samples were placed at 1 meter depth in mesh bags within the clear and white on black tarp covered stockpiles. Samples 1-8 were taken at installation in the first week of December at depth of 1 meter in the piles at the depth where AF36 inoculated sample bags were to be installed. Samples 9-16 were taken at the time of removal of sensors and inoculated bags in mid-March at 1 meter depth near inoculated bags. Samples 17-24 represent the contents of the bag containing the sensors and the AF36 inoculated samples.

Sample #	Timing	Pile #	stockpile info	mass(g)	B1 Aflatoxin (ppb)
1	Install	1	Clear	370	0
2	Install	2	Clear	455	0
3	Install	3	Clear	405	0
4	Install	4	Clear	410	0
5	Install	5	white/black	510	0
6	Install	6	white/black	510	0
7	Install	7	white/black	470	0
8	Install	8	white/black	360	0
9	Post-stockpile	1&2 -A	Clear	400	0
10	Post-stockpile	1&2 - B	Clear	400	2.7
11	Post-stockpile	3&4 - A	Clear	480	0
12	Post-stockpile	3&4 -B	Clear	380	0
13	Post-stockpile	5&6-A	white/black	375	0
14	Post-stockpile	5&6-B	white/black	355	0
15	Post-stockpile	7&8-A	white/black	425	0
16	Post-stockpile	7&8-B	white/black	480	0
17	Post-inoculated	1	Clear	390	0
18	Post-inoculated	2	Clear	385	0
19	Post-inoculated	3	Clear	490	0
20	Post-inoculated	4	Clear	410	0
21	Post-inoculated	5	white/black	460	0
22	Post-inoculated	6	white/black	580	0
23	Post-inoculated	7	white/black	440	0
24	Post-inoculated	8	white/black	505	0

Table 4. Relationship between relative humidity (and water activity) for: 1) in shell kernels in hulls; 2) hulls; and 3) in shell kernels. Green shaded area indicates moisture contents that are acceptable for stockpiling. However, it should be noted that relationship between water content and water activity has been shown to vary depending on how wetting/drying cycles are produced. This suggests that the most accurate measurement is water activity since it is directly related to microorganism growth potential. Red shaded area indicates moisture contents that are too wet.

		water content		
Relative humidity	Water activity	kernels+hulls	hulls	kernels
30	0.30	3.80	4.43	2.73
31	0.31	3.89	4.59	2.79
32	0.32	4.00	4.76	2.85
33	0.33	4.11	4.94	2.92
34	0.34	4.22	5.12	2.99
35	0.35	4.34	5.31	3.06
36	0.36	4.47	5.50	3.14
37	0.37	4.61	5.71	3.22
38	0.38	4.75	5.92	3.31
39	0.39	4.89	6.13	3.40
40	0.40	5.05	6.36	3.50
41	0.41	5.20	6.59	3.60
42	0.42	5.37	6.83	3.71
43	0.43	5.54	7.07	3.82
44	0.44	5.72	7.32	3.94
45	0.45	5.90	7.58	4.06
46	0.46	6.09	7.85	4.18
47	0.47	6.29	8.12	4.31
48	0.48	6.49	8.40	4.45
49	0.49	6.70	8.69	4.59
50	0.50	6.92	8.98	4.73
51	0.51	7.14	9.28	4.88
52	0.52	7.37	9.59	5.03
53	0.53	7.60	9.90	5.19
54	0.54	7.84	10.22	5.35
55	0.55	8.09	10.55	5.51
56	0.56	8.34	10.89	5.69
57	0.57	8.60	11.23	5.86
58	0.58	8.87	11.58	6.04
59	0.59	9.14	11.94	6.23
60	0.60	9.42	12.30	6.42
61	0.61	9.70	12.67	6.61
62	0.62	9.99	13.05	6.81
63	0.63	10.29	13.43	7.01
64	0.64	10.59	13.82	7.22
65	0.65	10.90	14.22	7.43
66	0.66	11.22	14.62	7.65
67	0.67	11.54	15.04	7.87
68	0.68	11.87	15.45	8.10
69	0.69	12.20	15.88	8.33
70	0.70	12.55	16.31	8.56
71	0.71	12.89	16.75	8.80
72	0.72	13.25	17.20	9.05
73	0.73	13.61	17.65	9.30
74	0.74	13.97	18.11	9.55
75	0.75	14.34	18.58	9.81
76	0.76	14.72	19.06	10.07
77	0.77	15.11	19.54	10.34
78	0.78	15.50	20.03	10.61
79	0.79	15.89	20.52	10.89
80	0.80	16.30	21.02	11.17
81	0.81	16.71	21.53	11.45
82	0.82	17.12	22.05	11.75
83	0.83	17.55	22.57	12.04
84	0.84	17.97	23.10	12.34
85	0.85	18.41	23.64	12.64
86	0.86	18.85	24.18	12.95
87	0.87	19.30	24.74	13.27
88	0.88	19.75	25.29	13.59
89	0.89	20.21	25.86	13.91
90	0.90	20.68	26.43	14.24
91	0.91	21.15	27.01	14.57
92	0.92	21.63	27.60	14.90
93	0.93	22.11	28.19	15.25
94	0.94	22.60	28.79	15.59
95	0.95	23.10	29.39	15.94
96	0.96	23.60	30.01	16.30
97	0.97	24.11	30.63	16.66
98	0.98	24.63	31.26	17.02
99	0.99	25.15	31.89	17.39
100	1.00	25.68	32.53	17.76

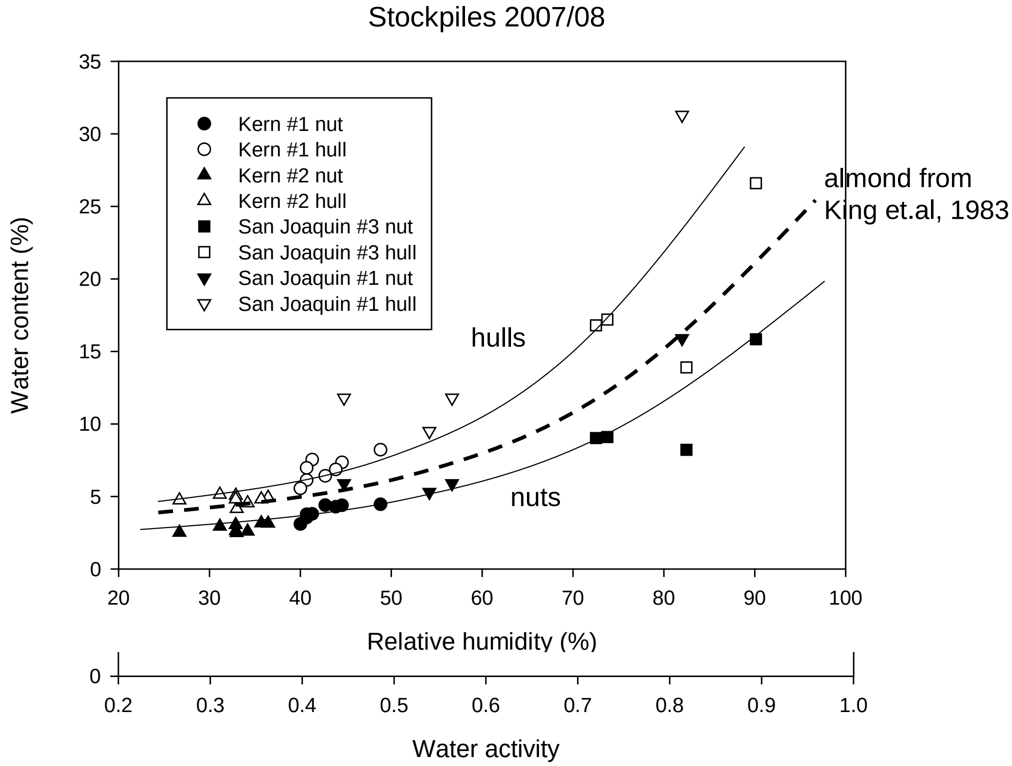


Figure 1. 2007/08 season: Relative humidity and water activity versus water content for nuts (including shell) and hulls from the Kern and San Joaquin County stockpiles. Data include cv. Nonpareil from Kern County as well as stockpile #1 and stockpile #3 from San Joaquin County. Dashed line is the approximate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

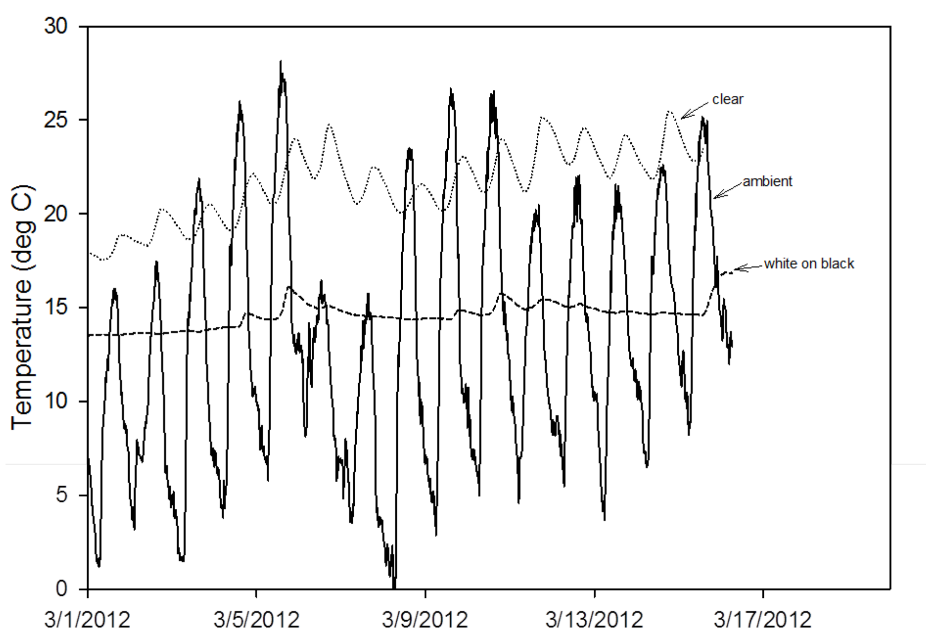
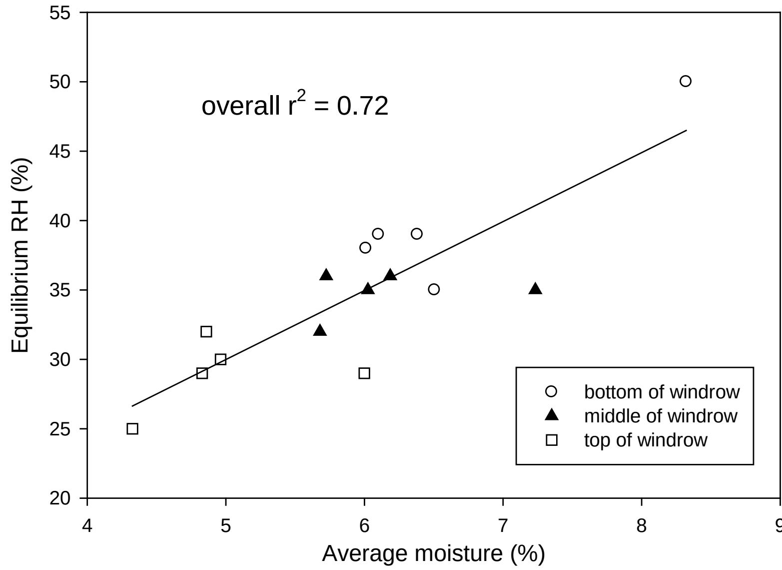


Figure 2. Temperature (in degrees Celsius) near top of stockpile under two different types of plastic cover in Kern County in March 2012. High temperatures under different tarp materials of 30 degrees Celsius correspond to 86 degrees Fahrenheit.



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

Figure 3. Average moisture content versus equilibrium relative humidity in container of nuts from three depths in windrows from Colusa County Aldrich orchard. Nuts were windrowed about 2 days after shaking and samples were taken 7 days later on date of harvest. Samples were field run samples of nuts and hulls.

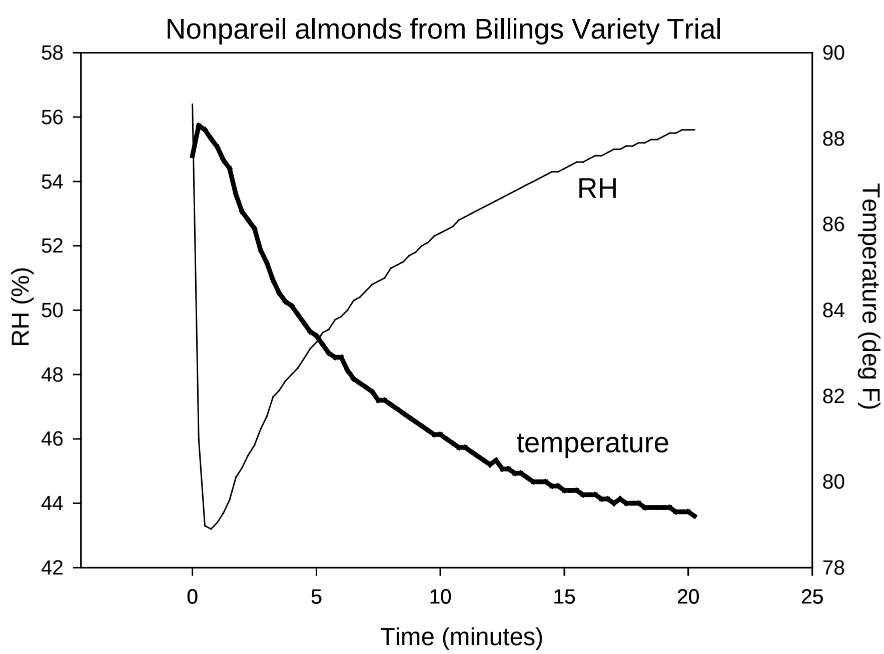


Figure 4. Temperature and relative humidity in container for a period of twenty minutes after enclosing field run samples of almond nuts and hulls. This figure points out the need to measure moisture content at a constant temperature and not shortly after taking them into a space with a large temperature difference from the sample temperature.

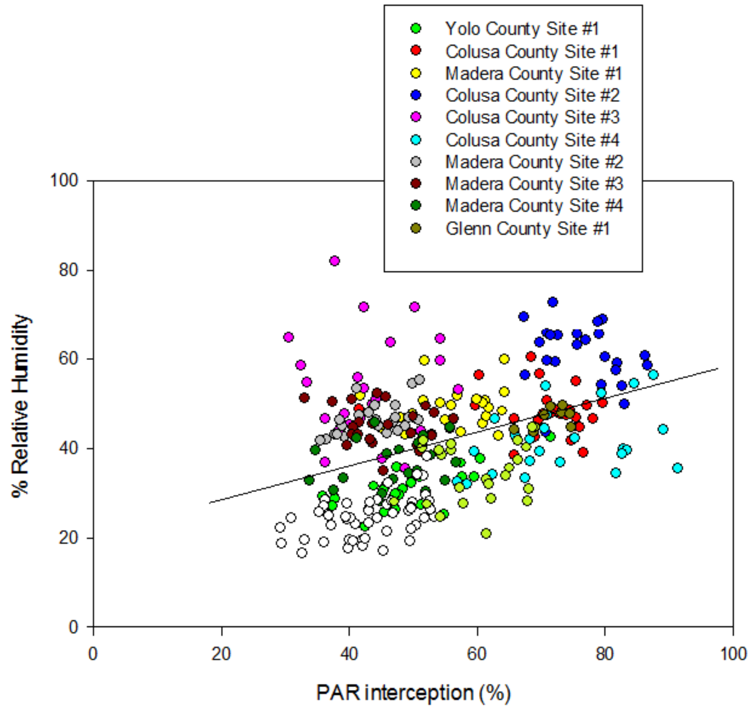


Figure 5. Midday canopy light interception (measured with Mule light bar) vs. relative humidity of in-hull nut samples in a container at room temperature. Samples are from 10 almond orchards from throughout state and include data from 2010, 2011 and 2012 seasons.

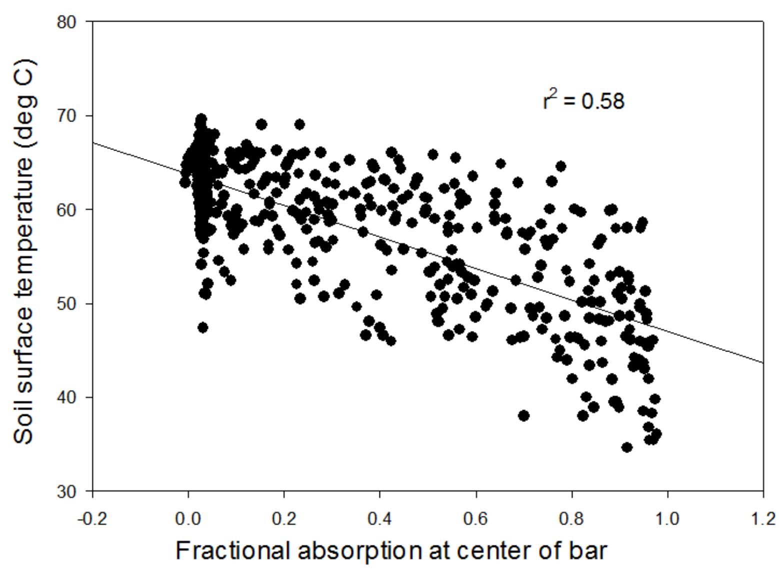


Figure 6. Fractional photosynthetically active radiation interception at the center of the mobile platform light bar versus soil surface temperature in the middle of the drive row. Data is from a Kern County orchard (Nonpareil, Wood Colony and Monterey) on July 1, 2012 with. Air temperature was approximately 31-34°C (88-93°F) during period measurements were taken. The soil surface temperature high of 70°C is approximately equal to 158°F.

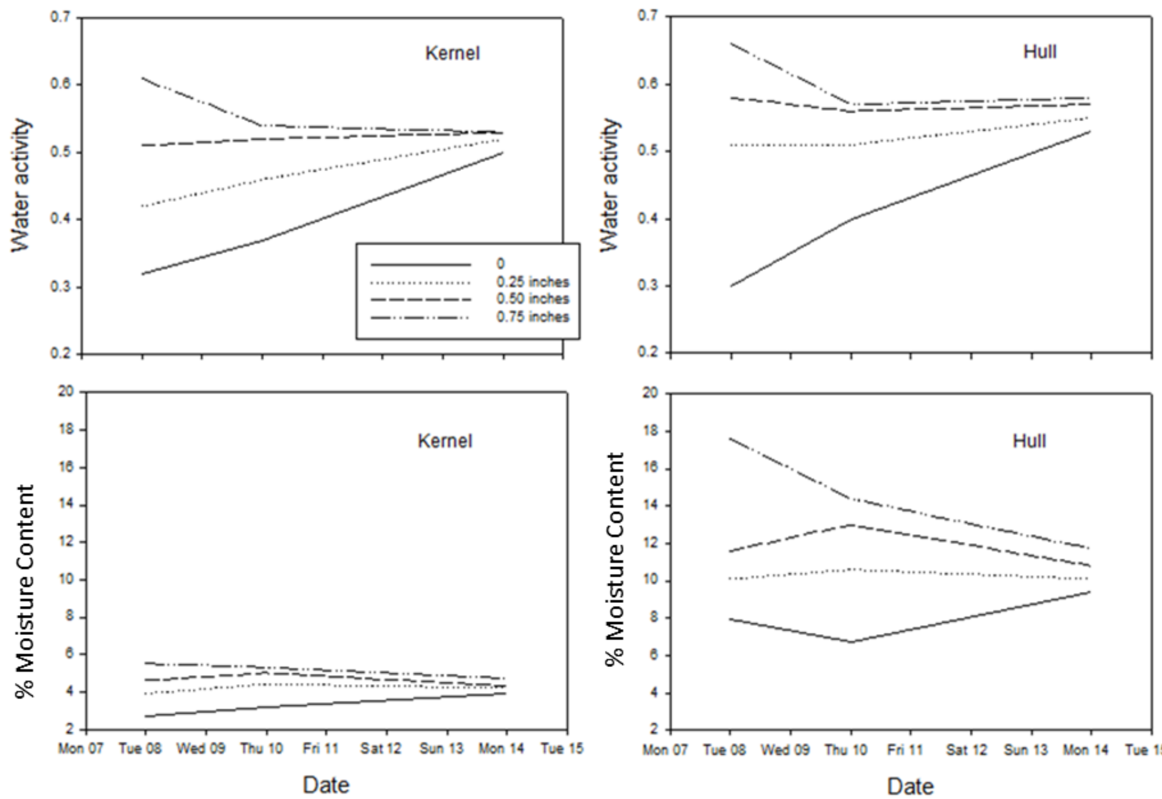


Figure 7. Water activity over 6 day drying cycle after simulated rainfall wetting for Nonpareil kernels (upper left) and hulls (upper right). Bottom left and bottom right figures represent percent moisture for kernel and hulls respectively over the course of the study. Inches of simulated rainfall that were applied are indicated in the legend (0, 0.25, 0.50 and 0.75 inches).