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Effect of highly processed calcined kaolin residues on apple productivity and quality

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ABSTRACT

Calcined kaolin-based particle films (PKPF) are effective in reducing insect, heat, photosynthetically active radiation (PAR) and ultraviolet radiation (UV) stress in plants due to the reflective nature of the heat-treated particles. The purpose of this study was to determine the effects of PKFP treatments applied at moderate (3%) and high rates (12% w/v) on apple physiology, yield and quality and the interaction with ambient ozone levels for a 6 year period. Fruit mass was increased by applications of PKPF at 3% and 12% in 4 of 6 years in non-irrigated treatments and in 2 of 6 years in irrigated treatments. Red fruit color was increased (lower hue angle) over the control in 5 of 6 years and in 2 of 5 years the 12% PKPF had improved red color over both the 0% and 3% PKPF non-irrigated treatments. PAR interception over 6 years, adjusted for LAI, was greatest for the control, least for the 12% PKPF, and 3% PKPF was intermediate. Reduced PAR interception below the canopy was likely due to greater PAR reflection within the canopy. Whole canopy temperature was significantly higher for the control (26 °C) and lower for the 3% and 12% PKPF treatments (24 °C). Fruit mass increased in the PKPF treatments, relative to the irrigated control treatment (%), with increasing maximum ozone levels during May. In laboratory studies, ozone degradation was greatest for alfalfa, least for calcined kaolin and the addition of alfalfa to calcined kaolin increased degradation proportionately. The present study confirms that calcined kaolin is an effective catalyst for ozone degradation and organic materials, such as alfalfa, are even more effective, due to the direct reaction with carbon molecules. Whole canopy gas exchange measurements (1000–1600 HR) over a 10 day period in 2011 indicated that the 2.7% PKPF + 0.3% alfalfa dust consistently had higher photosynthesis, 0.3% alfalfa was intermediate, while the control and 3% PKPF had the lowest photosynthesis rate. Whole canopy ozone degradation indicated that the 2.7% PKPF + 0.3% alfalfa dust consistently had the greatest ozone degradation, 3% PKPF and 0.3% alfalfa were intermediate and the untreated control had the least ozone degradation. There is evidence that the 0.3% alfalfa stimulated a small amount of microbial growth on the leaf surface while the 2.7% PKPF + 0.3% alfalfa stimulated a much greater amount of microbial growth. This synergistic effect may be due to the increased surface area in the particle film providing habitat for microbial populations and the reflection of UV by the particles that can be deleterious to microbial growth within that habitat. Data support the concept that chronic ozone damage is moderated to a significant degree by the use of surface treatments that catalyze ozone degradation in a particle film. The use of PKPF may be one tool to mitigate not only increased ozone stress but also heat stress from increased growing season temperatures in the future.

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1. Introduction

Kaolin-based particle films, specifically processed calcined kaolin (PKPF), have utility in reducing insect, heat, photosynthetically active radiation (PAR) and ultraviolet radiation (UV) stress in plants due to the reflective nature of the heat-treated particles (Glenn and Puterka, 2005). The particle film changes the plant's leaf/fruit texture and the reflected light signature of the plant resulting in deterrence of many pest insects. (Glenn and Puterka, 2005; D'Aquino et al., 2011; Leskey et al., 2010; Pascual et al., 2010; Sackett et al., 2007). The particle film alters reflected infrared (IR), PAR, and UV radiation compared to an untreated plant (Glenn et al., 2002).

Reflection of IR reduces canopy temperature and, consequently, potential transpiration (Boari et al., 2015; Glenn, 2010; Jifon and Syvertsen, 2003; Moftah and Al-Humaid, 2005; Steiman et al.,

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2011). The reflection of PAR by the particle film at the leaf level is compensated in varying degrees by diffusion of PAR into the interior of the canopy (Glenn and Puterka, 2007; Rosati et al., 2007; Wűnsche et al., 2004). The combined particle film effects of reduced canopy temperature and increased diffusion of PAR into the interior of the canopy can increase whole canopy photosynthesis (Glenn et al., 2003; Glenn, 2009, 2010) or have no effect (Wűnsche et al., 2004). The effect of PKPF on yield studies is similarly inconsistent. Excluding sunburn effects, many studies show increased yield and fruit quality of horticultural crops (Aly et al., 2010; Glenn, 2009, 2010; Glenn and Puterka, 2007; Glenn et al., 2001, 2003, 2005; Lapointe et al., 2006; Cantore et al., 2009; Pace et al., 2007; Wand et al., 2006; Saavedra et al., 2006; Steiman and Bittenbender, 2007; Boari et al., 2014; Ergun, 2012; Khaleghi et al., 2015; Lalancette et al., 2005; Shellie and Glenn, 2008; Shellie and King, 2013; Sugar et al., 2005a,b; Srinivasa Rao, 1985). There are also studies demonstrating no or negative effects of PKPF on fruit yield and quality (Schupp et al., 2002; Gindaba and Wand, 2005; Kahn and Damicone 2008; Lombardini et al., 2005; Russo and Diaz-Perez, 2005). Based on the methods of these studies it is most likely that the particle film residue density ranged from 1 to 4 g·m^{-2} based on application rates ranging from 12 to 50 kg/ha or 1.5 to 6% (w/v).

Jones (1963) demonstrated that hydrous kaolin (kaolinite) provided slight protection of tobacco from ozone damage but charcoal and diatomaceous earth resulted in almost complete protection from ozone damage. Charcoal has a very high surface area (674 m^2/g) (Dunicz, 1961); diatomaceous earth has moderate surface area (21 m^2/g Tsai et al., 2006) and the calcination process that dehydrates kaolinite reduced the surface area from 19 to 17 m^2/g (Plešingerová et al. 2011). Charcoal degrades ozone upon contact; the carbon is oxidised to carbon monoxide and carbon dioxide, resulting in destruction of the ozone molecule. (Deitz and Bitner, 1973). Glenn et al. (2015) have demonstrated that the mass of microbial DNA extracted from leaf surfaces is linearly related to the amount of kaolin residue on the leaf surface and the amount of microbial DNA on kaolin treated leaves is 2–5 times greater than untreated control treatments. According to Jones (1963) inert particulate materials serve as catalysts to degrade ozone in an exothermic reaction. Therefore both carbonaceous materials, such as microbial mass, and inert particulates, such as kaolin and other clay materials, can degrade ozone to some extent. Leaf surface microbial growth is limited by the resources available to the organisms from the leaf and the environmental conditions of the leaf. PKPF is highly reflective of UV radiation which provides a reduced UV habitat in addition to increased surface area for microbial colonization. Nutrients are limiting for microbial growth and addition of low carbon:nitrogen (C:N) materials, such as alfalfa powder, may provide nutrients to increase microbial growth and further increase ozone degradation at the leaf surface.

The purpose of this study was to determine the effects of highly processed calcined kaolin particle film residues applied at higher rates (12% w/v) than generally documented and infer the mechanisms of action. The role of ozone degradation was also investigated in the yield and quality response of apple to PKPF applications by adding alfalfa powder to field studies to evaluate the effect of a highly biodegradable material with a low C:N ratio on microbial growth and ozone degradation.

2. Methods and materials

2.1. Field plots and treatment application

The apple orchard was a moderate density planting (500·ha^{-1}) of 'Empire'/'Malling7A' planted in 1992 at the USDA/ARS Appalachian Fruit Research Station, Kearneysville, WV. Tree water requirements were based on 70% of pan evaporation (Glenn, 1995, 1999). Irrigation treatments consisted of two drip emitters per tree providing the daily water needs. Treatments were randomly assigned in 2005 in a split-plot block design with irrigation as the main plot and PKPF treatment as the subplot with six, two tree replicates. In all years, the trees were hand-thinned post-bloom. Trees received a PKPF treatment or were not treated. All treatments were over-sprayed with conventional pesticides to protect from disease or insect damage. Conventional orchard practices were used in tree training, mowing, nutrition, and weed control.

Apple trees received applications of a highly reflective, white, calcined hydrophilic particle based on kaolin mineral (PKPF treatment was Surround WP$^{\text{TM}}$, NovaSource, a division of Tessenderlo Kerley Inc. Phoenix, AZ) in addition to a conventional pesticide spray program. The mineral was processed to a bright white color of >90% reflectance, with mean particle size <2 μm in diameter. PKPF was applied at the rate of 25 kg/ha and 100 kg/ha for 3% and 12% (w/v) during the 2005–2010 growing seasons. The PKPF treatments were applied in a spray volume of 833 L·ha^{-1} (approximately 50% of tree row volume) using an air blast sprayer at a ground speed of 3.2 km/hr. There was an untreated control treatment. PKPF treatments were applied every 2 weeks following petal fall until 2–3 weeks before harvest.

In 2011 and 2012 new treatments were randomly assigned in a split-plot block design with irrigation as the main plot and PKPF treatment as the subplot with four double-tree replicates (3% w/v PKPF, 2.7% w/v PKPF + 0.3% w/v alfalfa powder (Now Foods, Bloomingdale, IL; C:N = 18:1), 0.3% w/v alfalfa powder or untreated). Trees were managed as before except that summer pruning was conducted in 2012 and the pruning weights determined.

2.2. Field measurements

At harvest, all fruit were weighed and counted for each tree in a plot. Fruit from each tree were processed with an electronic grader that counted and weighed each fruit. Ten fruit were sub-sampled and the hue angle measured on 4 sides around the equator of the fruit for 2005–2010.

Canopy light transmission was measured using two 1-m light bars (LI191SA; Licor, Lincoln, NE). Canopy light transmission within 1 h of solar noon was measured by placing the reference sensor horizontally in an open area and placing the analysis sensor horizontally beneath the tree. Four measurements within the shadow of the tree were recorded. These data were collected once in each year (2005–2010). Following harvest, the trees were covered with a netting to capture all the leaves when they abscised. The leaves were collected and air-dried at 70 °C for approximately 1 week. At sampling, a subsample of approximately 3 kg fresh weight was separated, leaf area was measured, and the ratio of air-dried weight:leaf area calculated. This ratio was used to convert the total air-dried weight of each tree to total leaf area. Leaf area index (LAI) was the quotient of the total leaf area divided by the area of the canopy shadow measured within one hour of solar noon.

The residue on leaf samples was measured in August and September 2005–2010 with the exception of 2006 preceding re-application. Ten leaves per tree were detached for measurement. Pre-weighed tissue paper was wetted and used to wipe the upper and lower surfaces until no residue was visible. The pre-weighed tissues were air dried and the added weight of the leaf residue determined. The leaf residue mass was divided by the leaf area of the combined 10 leaves. Data were collected across the PKPF treatments and pooled over irrigation treatments. In 2011 and 2012, 10 leaves per tree were washed with sterile water and sonicated to extract the surface residue and microflora according to Glenn et al. (2015). The residue amount and DNA content of the residue were determined following Glenn et al. (2015). The DNA content of the