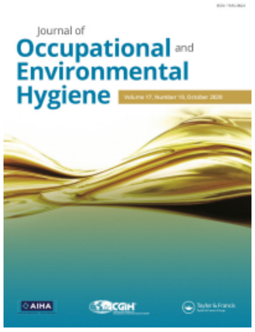

Journal of Occupational and Environmental Hygiene

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/uoeh20

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To cite this article: Danielle Dillane & Jo Anne G. Balanay (2021) Comparison between EPA UV index app and UV monitor to assess risk for solar ultraviolet radiation exposure in agricultural settings in Eastern North Carolina, Journal of Occupational and Environmental Hygiene, 18:1, 16-27, DOI: 10.1080/15459624.2020.1842880

To link to this article: https://doi.org/10.1080/15459624.2020.1842880

Published online: 07 Dec 2020.

JOURNAL OF OCCUPATIONAL AND ENVIRONMENTAL HYGIENE
2021, VOL. 18, NO. 1, 16–27
https://doi.org/10.1080/15459624.2020.1842880

Comparison between EPA UV index app and UV monitor to assess risk for solar ultraviolet radiation exposure in agricultural settings in Eastern North Carolina

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ABSTRACT

Agricultural workers are exposed to solar ultraviolet (UV) radiation due to the significant amount of time spent working outdoors. Risk information on UV exposure from the EPA SunWise UV Index mobile app is conveniently available for timely advice on risk management, but its reliability is unknown. The purpose of this study was to determine the reliability of the EPA UV Index app in providing accurate risk information to reduce UV exposure and prevent related illnesses among agricultural workers in eastern North Carolina. UV radiation effective irradiance (UV_{eff}) indices were datalogged at two agricultural sites using radiometers from April–August 2019 and were assigned to risk levels (low, moderate, high, very high, extreme) based on the ACGIH® Threshold Limit Values (TLVs®). The UV index (UV_{app}) and its corresponding risk level were obtained using the app. Hourly UV_{app}-based risk level assignments were time-matched to their corresponding UV_{eff}/TLV-based risk level assignments (871 pairs) and analyzed using cross tabulation by determining the percentage of hourly UV_{eff}/TLV-based risk levels ("gold standard") with the same hourly UV_{app}-based risk levels, with a larger percentage indicating higher app reliability. Results showed that the app correctly identified 100% of low risk conditions, but its reliability decreased as the UV risk condition became more severe. The app correctly identified 0% of moderate, high and very high risk conditions but instead assigned 100% of them to lower risk levels (30–100% as low risk, 5–70% as moderate risk), indicating that the app was less protective in assessing UV risk. The app correctly identified 0.6% of extreme risk conditions but assigned 99.4% of them to lower risk levels (9.4% as low, 29.7% as moderate, 24.6% as high, 35.8% as very high). It is concluded that the performance of the EPA UV Index app in assessing occupational UV risk is not protective of workers particularly for high risk conditions, and that the use of the app for the assessment of risk to UV exposure in agricultural settings is not recommended.

KEYWORDS
Agriculture; occupational exposure; outdoor workers; risk assessment; sun exposure; UVI

Introduction

Agricultural workers spend a significant portion of their work day under the sun, exposing them to solar ultraviolet (UV) radiation for extended periods of time and increasing their risk of UV-related illnesses. Exposure to solar UV radiation is recognized as the main cause of skin cancer (Armstrong and Kricker 2001) and can cause sunburn that may increase skin cancer risk (Glanz et al. 2007). Outdoor workers have nearly two-fold relative risk of skin cancer compared to indoor workers (Schmitt et al. 2011) and are 43% more likely to develop basal cell carcinoma (Bauer et al. 2011). Occupational solar UV exposure significantly contributes to the overall UV dose, increasing workers' risk of skin cancer (Milon et al. 2014). Specifically, farmers were found to have increased incidence and risk of recurrence of basal cell carcinoma (Szewczyk et al. 2016). Studies (Vishvakarman et al. 2001; Thieden et al. 2005; Hammond et al. 2009) found that various outdoor workers have UV doses that exceeded the 0.3 standard erythemal dose (SED) recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP 2004). Previous studies have measured UV exposure among outdoor workers, including farmers, using personal UV dosimeters in several countries, such as Australia, Austria, Italy, Spain, and Switzerland, showing exposures exceeding

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occupational exposure limits (Gies and Wright 2003; Schmalwieser et al. 2010; Siani et al. 2011; Modenese et al. 2019; Serrano et al. 2009; Serrano et al. 2013; Milon et al. 2007). Beck et al. (2018) assessed the solar UV exposure of groundskeepers using area monitoring in the United States (U.S.). However, there are currently no published studies conducted in the U.S. that measured UV exposure in an agricultural setting.

Occupational exposure to UV radiation is assessed by measuring UV in the spectral region between 180 and 400 nm, which is known to cause acute adverse health effects including erythema and photokeratitis (ACGIH 2019). A common metric used for UV exposure assessment is the effective irradiance in milliwatts per square centimeter (mW/cm^2), which can be directly measured with a UV radiometer with a built-in spectral response that mimics the erythemal action spectrum (ACGIH 2019). The American Conference of Governmental Industrial Hygienists (ACGIH®) has established threshold limit values (TLVs®) for direct ocular and skin exposures to UV based on daily exposure durations (ACGIH 2019). Although technical guidance on worker protection from UV light with respect to laser hazards is available (OSHA 2020), there are no regulatory exposure limits to UV as mandated by the Occupational Safety and Health Administration (OSHA).

Other sources of UV exposure information include forecasts of the Global Solar UV Index (UVI) provided by several national meteorological services, such as the U.S. National Weather Service (NWS 2020). The UVI is readily available to employers from publicly broadcasted weather forecasts, serving as a useful tool to assess UV exposure risk of outdoor workers. A few studies estimated the occupational UV exposure of outdoor workers using UV data from meteorological satellites or land-based stations (Boniol et al. 2015; Arjona et al. 2016).

The U.S. Environmental Protection Agency (EPA) released the EPA SunWise UV Index application (hereafter referred to as EPA UV Index app) for mobile devices that enables any user to obtain the daily and hourly forecast of the expected intensity of solar UV radiation for a local geographic area (EPA 2015; EPA 2020). Hourly UVI forecast, with values from 1 to 11+, from 8 AM to 6 PM, is provided by the app. The UVI is calculated by the U.S. National Weather Service using a computer model that relates the strength of solar UV radiation reaching the ground to forecasted stratospheric ozone concentration, forecasted cloud amounts and ground elevation on a next day basis (EPA 2016, EPA 2019b). The app categorizes the UVI values into five risk levels ranging from low to extreme (EPA 2015; EPA 2019b) and also provides recommendations for sun protection based on the risk category (EPA 2019c). The app is expected to be a useful tool for planning outdoor activities with sun safety in mind (EPA 2019c). Considering that the prevalence of sunscreen use and shade-seeking as preventive measures is low among agricultural workers (Ragan et al. 2019), the app is potentially useful to increase agricultural worker awareness and to monitor their risk of UV exposure in their specific field location and, consequently, in decreasing risk of UV-related illnesses, if the risk information provided by the app is accurate.

Although UVI forecasts derived from meteorological data are easily accessible, local UV measurements may provide a more realistic assessment of UV exposure levels (Corrêa et al. 2010). Worker exposure and risk information obtained from actual worksite measurements using instrumentation-based exposure assessment methods is recognized to provide the most accurate worker exposure information. For example, OSHA recognizes that the most accurate information on workers' heat exposure is obtained by measuring heat stress at the worksite (CDC 2018). It is expected that onsite UV monitoring using appropriate UV radiometers will produce the most reliable work exposure data. However, onsite exposure measurements may not always be readily available for workplace exposure assessments for several reasons (e.g., lack of financial resources to purchase expensive instruments and/or hire trained personnel), which are likely issues in agricultural worksites (Dillane and Balanay 2020).

It is important that timely advice on UV risk be readily available as this can prevent acute (e.g., skin erythema) and chronic (e.g., skin cancer) illnesses. Daily risk information on UV exposure from mobile apps, such as the EPA UV Index, can be more readily available for worker protection compared to instrumentation-derived risk data, but their accuracy for workplace application is unknown. A recent study investigated the reliability of heat stress data from the OSHA-NIOSH Heat Safety Tool app in assessing heat stress risk in an agricultural setting compared to data from WBGT monitors, and concluded that the app is not protective of the workers with heavy and very heavy workloads (Dillane and Balanay 2020). Therefore, it is important to assess whether the UVI risk advisory provided by the EPA UV Index app is applicable to the agricultural workforce and whether it would either underestimate or overestimate risk.

A few studies have used mobile apps related to UV exposure in different ways, for example, as a UV exposure diary for non-workplace settings (Hacker et al. 2018) and a tool for assessing public understanding of the UVI (Nicholson et al. 2019). To our knowledge, there is currently no published study that assessed the reliability of the EPA UV Index app for use in exposure monitoring and risk assessment for occupational UV exposure, and that compared mobile app information with UV exposure data derived from onsite instrumentation-based exposure measurements. This information is crucial in determining if the app can be reliably used as an alternative risk assessment method that is cheaper and readily accessible to agricultural and other outdoor workers for solar UV exposure prevention. It is important for workers to know the extent of their UV exposure and its associated health risk in order for them to take the appropriate preventive measures.

The main purpose of this study was to determine the reliability of the EPA UV Index app in providing accurate UV exposure risk information for agricultural workers in eastern NC. This study specifically aimed to: (1) assess the UV exposure of agricultural workers compared to the ACGIH Threshold Limit Values (TLVs); and (2) compare the UV exposure risk levels obtained from the EPA UV Index app to those derived from UV exposure measurements assessed using the ACGIH TLV.

Methods

Study sites

Two agricultural sites in the rural eastern NC within or near Pitt County, in consultation with the Pitt County Cooperative Extension Center, were selected and recruited as study sites. One site was located in Ayden, NC in Greene County, and the other site was located in Tarboro, NC in Pitt County. These were the same study sites monitored for heat stress in a recent study and were described in more detail elsewhere (Dillane and Balanay 2020). The straight-line distance between the two study sites was approximately 19.8 miles, as determined using Google Earth (version 7.3, Google, Mountain View, CA). Area monitoring was conducted to assess occupational exposure to solar UV at these sites.

Ultraviolet (UV) radiation monitoring

UV radiation monitoring was conducted by using digital datalogging radiometers (PMA2100, Solar Light Co., Inc., Glenside, PA) and UV digital sensors (PMA2102C, Solar Light Co., Inc., Glenside, PA) with spectral response close to the erythemal action spectrum. Two radiometers were deployed, one at each study site on the same monitoring days. Each radiometer was positioned at a height of 3.5 ft from the ground using a tripod. The radiometers were factory-calibrated within 2 months prior to data collection. A trial run for a side-by-side comparison of radiometer readings was conducted on April 12, 2019 from 9:40 AM to 3:40 PM and found strong correlation ($r = 0.995$) between 1-min instrument readings but showed an average difference of 0.0026 mW/cm^2. Readings for both radiometers were adjusted to reduce the measurement difference between the radiometers to 0.00 mW/cm^2 without affecting the correlation ($r = 0.995$) between instrument readings. For each monitoring day, the effective irradiance, UV_{eff} (mW/cm^2) was datalogged every minute for 8–11 hr within the working period of 8:00 AM–7:00 PM. Monitoring was conducted for 45 days within the period of April 15 to August 9, 2019, to cover most of the summer season. The hourly mean UV_{eff} indices were calculated and compared to the ACGIH TLV for the UV radiation effectiveness irradiance (ACGIH 2019). The maximum exposure time, t_{max} (s), for each hourly mean UV_{eff} was calculated using the following equation (ACGIH 2019):

$$t_{max}[s] = 0.003 \ [J/cm^2]/UV_{eff}[W/cm^2] \qquad (1)$$

Comparison of UV_{eff} with ACGIH TLVs

The ACGIH TLV for UV radiation effective irradiance considers the duration of exposure per day (ACGIH 2019). Hourly mean UV_{eff} indices were compared to the TLV of 0.0008 mW/cm^2 for 1-hr exposure duration to determine if this exposure limit was exceeded at any time throughout the day. Daily mean UV_{eff} indices were also compared to the TLV of 0.0001 mW/cm^2 for 8-hr exposure duration (ACGIH 2019).

Use of mobile app

The EPA SunWise UV Index app (version 4.1, Environmental Protection Agency, Washington D.C.) was used to collect data on predicted hourly UVI rating (1 to 11+), hereafter referred to as UV_{app}, and its corresponding risk level from 9:00 AM to 6:00 PM (EPA 2015). The app categorizes UVI values into five risk levels: low ($\leq$2), moderate (3–5), high (6–7), very high (8–10), and extreme (11+) risk (EPA 2004; EPA 2019a). App data were recorded between 6:00–8:00

Table 1. UV_{eff} index range (mW/cm^2) used to assign UV risk level.

		TLV Basis for UV_{eff} Index Range	
Risk Level	UV_{eff} Index Range (mW/cm^2)	TLV by Exposure Duration*	Percentage of 1-hr TLV
Low	<0.0008	$<$1-hr TLV	$<$100% of 1-hr TLV
Moderate	0.0008 - <0.0017	1-hr TLV to $<$ 30-min TLV	100 to $<$200% of 1-hr TLV
High	0.0017 - <0.0033	30-min TLV to $<$ 15-min TLV	200 to $<$400% of 1-hr TLV
Very High	0.0033 - <0.005	15-min TLV to $<$ 10-min TLV	400 to $<$600% of 1-hr TLV
Extreme	≥0.005	$\geq$10-min TLV	$\geq$600% of 1-hr TLV

*ACGIH TLV: 1-hr exposure duration = 0.0008 mW/cm^2; 30-min exposure duration = 0.0017 mW/cm^2; 15-min exposure duration = 0.0033 mW/cm^2; 10-min exposure duration = 0.005 mW/cm^2 (ACGIH 2019)

AM of each monitoring day prior to instrument deployment. Zip codes were used in the app to obtain data that were specific to the study site location: 28513 for Ayden and 27886 for Tarboro. The straight-line distances between the study site and its corresponding NOAA regional weather station, from which the location-specific app data was obtained, were 6.8 and 6.3 miles for the Tarboro and Ayden sites, respectively.

Assignment of TLV-based risk levels to UV_{eff} indices

Table 1, which specifies ranges of UV_{eff} indices for each risk level, was developed for this study to assign risk levels to the hourly mean UV_{eff} indices obtained from UV monitoring. The risk level categories (low to extreme) used in Table 1 were the same as those used in the EPA UV Index app for easier comparison. The UV_{eff} index criteria in Table 1 were derived from the ACGIH TLVs for four exposure durations: 0.0008 mW/cm^2 for 1-hr, 0.0017 mW/cm^2 for 30-min, 0.0033 mW/cm^2 for 15-min, and 0.05 mW/cm^2 for 10-min. Alternatively, the UV_{eff} index criteria may also be based on percentage of the ACGIH TLV for 1-hr exposure duration, with increasing percentage from $<$100 to $\geq$600% as the risk level became more severe (Table 1). Dillane and Balanay (2020) similarly used the ACGIH TLVs for heat stress and Morris et al. (2019) study's heat stress zones to assign risk levels based on measured WBGT index.

Comparison between UV monitoring and app data

Comparison was conducted between the hourly UV_{eff}/TLV-based risk obtained from UV monitoring and the hourly UV_{app}-based risk for UV exposure. Only data pairs (e.g., UV_{eff}/UV_{app}) that were time-matched (i.e., same day, same hour, same location) were used for comparison. The time-matched hours used were between "9:00 AM" and "6:00 PM", and the number of hours per day has an average of 10.5 ± 0.8 hours (ranging from 6 to 11 hours). Considering the UV_{eff} obtained using onsite radiometers as the "gold standard" for occupational UV exposure assessment, the reliability of the app in assessing workplace risk to UV exposure was determined by the percentage of hourly UV_{eff}-based risk levels that had the same hourly UV_{app}-based risk levels assigned by the app. The aim was to compare the similarity between assigned risk levels from UV monitoring and from the app, with a higher percentage of agreement on risk assignments indicating higher app reliability.

Data analysis

The daily mean, minimum, maximum, and standard deviation of both hourly UV_{eff} and UV_{app} were determined. Analysis of variance (ANOVA) was conducted to compare the following indices: (1) daily mean UV_{eff} by location and month; (2) daily maximum UV_{eff} by location; (3) hourly mean UV_{eff} by month and time of day; (4) hourly maximum exposure time (t_{max}) by month and time of day; (5) daily mean UV_{app} by location and month; (6) daily maximum UV_{app} by location; and (7) hourly mean UV_{app} by month and time of day. Cross tabulation was used to analyze the relationship between risk level categories based on instrumentation-obtained UV_{eff} and those obtained from the app. The Statistical Package for Social Sciences (SPSS version 25, IBM, Armonk, NY) was used to analyze the data. Results with $P < 0.05$ were considered statistically significant.

Results

UV_{eff} indices

The hourly mean UV_{eff} for the entire study period ranged from 0.0006–0.0299 mW/cm^2, with an overall mean ± standard deviation of 0.0120 ± 0.0067 mW/cm^2 (n = 942), while the daily mean UV_{eff} ranged from 0.0063–0.0162 mW/cm^2, with an overall mean of 0.0120 ± 0.0019 mW/cm^2 (n = 90). Comparing the same days for both study sites, the overall daily mean UV_{eff} for Ayden (0.0124 ± 0.0016 mW/cm^2, range = 0.0074–0.0159 mW/cm^2, n = 45) was not significantly different (F = 3.38, P = 0.07) from that for Tarboro

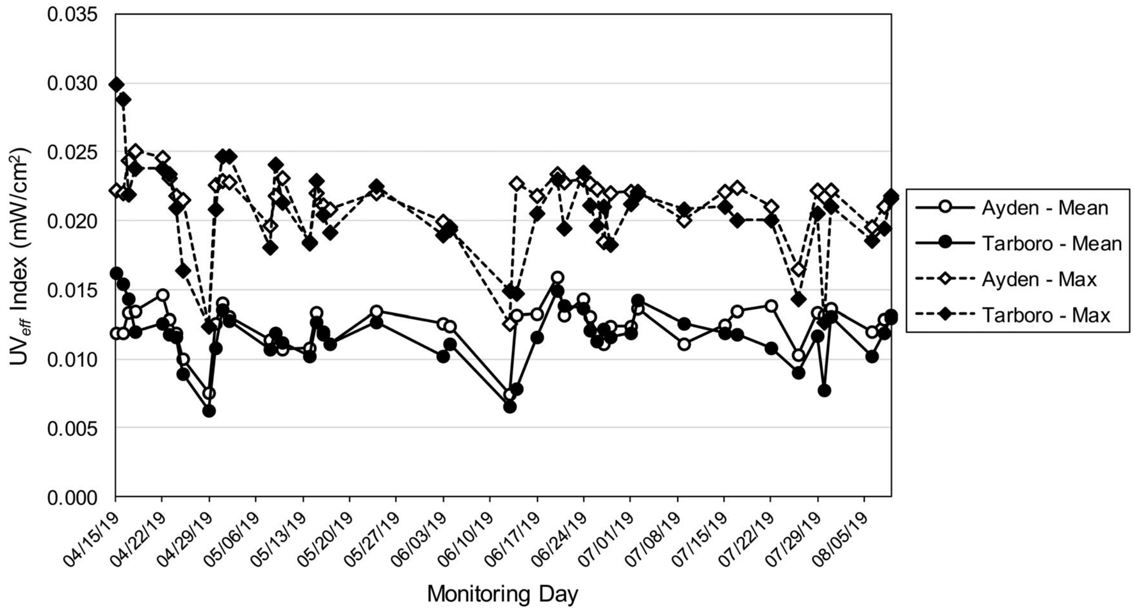

Figure 1. Daily mean and maximum UV_{eff} Index (mW/cm^2) by monitoring day and study site.

(0.0117 ± 0.0021 °C, range = 0.0063–0.0162 mW/cm^2, n = 45). Similarly, the overall mean of daily maximum UV_{eff} for Ayden (0.0214 ± 0.0025 mW/cm^2) was not significantly different ($F = 1.36$, $P = 0.25$) from that for Tarboro (0.0206 ± 0.0035 mW/cm^2). The highest hourly mean UV_{eff} (0.0299 mW/cm^2) was measured at Tarboro on April 15, 2019, at 1 PM, while the highest daily mean UV_{eff} (0.0162 mW/cm^2) was also measured at Tarboro on the same day. Figure 1 shows the daily mean and maximum UV_{eff} by monitoring day for both sites and demonstrates fluctuating index values but does not show either a decreasing or increasing trend from April to August.

Table 2 shows the hourly and daily mean UV_{eff} by month (April to August) and time of the day (morning, noon, afternoon and evening). Both the hourly ($F = 0.03$, $P = 1.00$) and daily ($F = 0.02$, $P = 1.00$) mean UV_{eff} were not significantly different among the monitored months. The hourly mean UV_{eff} were significantly different ($F = 523.95$, $P < 0.01$) by time of the day. The evening has the lowest mean UV_{eff} (0.0033 ± 0.0015 mW/cm^2) followed by morning (0.0081 ± 0.0038 mW/cm^2), while noon has the highest (0.0184 ± 0.0037 mW/cm^2).

Comparison of UV_{eff} with ACGIH TLV

Table 2 shows the mean UV_{eff} and the number and percentage of hourly and daily mean UV_{eff} that exceeded the 1-hr TLV (0.0008 mW/cm^2) and 8-hr TLV (0.0001 mW/cm^2), respectively, by month and time of day. Overall, 99.9% of hourly UV_{eff} (n = 941) exceeded the 1-hr TLV, while 100% of daily UV_{eff} (n = 90) exceeded the 8-hr TLV. The only hourly mean UV_{eff} (n = 1) that did not exceed the 1-hr TLV occurred in May during the evening (6 PM). Although the hourly mean UV_{eff} for the evening was the lowest among the times of the day, majority (99.4%) of the indices measured during the evening hours exceeded the 1-hr TLV.

Maximum exposure time (t_{max})

Table 3 shows the maximum exposure time (t_{max}) calculated for each hourly mean UV_{eff} index measured (n = 942), with an average of 7.40 (± 8.09) min, ranging from 1.67 min to 1.45 hr. By month, the mean t_{max} calculated was the shortest for August (6.21 ± 5.08 min) and the longest for April (8.73 ± 10.25 min). The difference in mean t_{max} values by month was statistically significant ($F = 3.23$, $P = 0.01$). By time of day, the mean t_{max} calculated was the shortest for noon hours (2.89 ± 0.96 min, ranging from 1.7–10 min) and the longest for the evening hours (20.00 ± 12.18 min, ranging from 8.3–89 min). The difference in mean t_{max} values by time of day was also statistically significant ($F = 358.20$, $P < 0.01$).

UV_{app} index from mobile app

The hourly UV_{app} and the corresponding heat stress risk level were obtained from the EPA's SunWise UV Index app for both study sites. The hourly UV_{app} for the entire study period ranged from 1–11, with an overall mean of 5.4 ± 2.8 (n = 899), while the daily

Table 2. Mean Ultraviolet Effective Irradiance (UV_{eff}) Index and number and percentages of hourly and daily mean UV_{eff} Index exceeding ACGIH Threshold Limit Values (TLV) for UV radiation effectiveness irradiance by month and time of day.

Parameter	Hourly Mean UV_{eff} Index (mW/cm^2)	Hours Monitored (N)	Hours Exceeding TLV [A]		Daily Mean UV_{eff} Index (mW/cm^2)	Days Monitored (N)	Days Exceeding TLV [B]	
			n	%			n	%
Month								
April	0.0119 ± 0.0076	214	214	100	0.0120 ± 0.0025	20	20	100
May	0.0120 ± 0.0068	215	214	99.5	0.0120 ± 0.0011	20	20	100
June	0.0119 ± 0.0064	247	247	100	0.0120 ± 0.0022	24	24	100
July	0.0120 ± 0.0062	206	206	100	0.0121 ± 0.0017	20	20	100
August	0.0122 ± 0.0062	60	60	100	0.0122 ± 0.0011	6	6	100
Time of Day[C]								
Morning	0.0081 ± 0.0038	251	251	100	—	—	—	—
Noon	0.0184 ± 0.0037	180	180	100	—	—	—	—
Afternoon	0.0152 ± 0.0052	357	357	100	—	—	—	—
Evening	0.0033 ± 0.0015	154	153	99.4	—	—	—	—
Overall	0.0120 ± 0.0067	942	941	99.9	0.0120 ± 0.0019	90	90	100

[A]ACGIH TLV for 1-hr exposure duration = 0.0008 mW/cm^2
[B]ACGIH TLV for 8-hr exposure duration = 0.0001 mW/cm^2
[C]Morning – 8 AM to 11 AM; Noon – 11 AM to 1 PM; Afternoon – 1 PM to 5 PM; Evening – 5 PM to 7 PM

Table 3. Maximum exposure time (t_{max}, min) for hourly mean Ultraviolet Effective Irradiance (UV_{eff}) Index by month and time of day.

Parameter	Hours Monitored (N)	t_{max} (min) Mean	Standard Deviation	Minimum	Maximum
Month					
April	214	8.73	10.25	1.67	62.16
May	215	8.04	9.96	2.02	86.89
June	247	6.75	6.08	2.13	34.81
July	206	6.46	5.65	2.23	34.47
August	60	6.21	5.08	2.29	27.87
Time of Day[A]					
Morning	251	8.07	4.49	2.84	22.92
Noon	180	2.89	0.96	1.71	10.01
Afternoon	357	3.77	1.52	1.67	11.30
Evening	154	20.00	12.18	8.34	86.89
Overall	942	7.40	8.09	1.67	86.89

[A]Morning – 8 AM to 11 AM; Noon – 11 AM to 1 PM; Afternoon – 1 PM to 5 PM; Evening – 5 PM to 7 PM

mean UV_{app} ranged from 3.5–6.4, with an overall mean of 5.4 ± 0.6 (n = 90). Comparing the study sites, the overall daily mean UV_{app} for Ayden (5.5 ± 0.6, range = 3.8–6.3, n = 45) was not statistically different (F = 0.24, $P = 0.63$) from that for Tarboro (5.4 ± 0.6, range = 3.5–6.4, n = 45). Likewise, the overall mean of daily maximum UV_{app} for Ayden (9.2 ± 0.9) was not statistically different (F = 0.12, $P = 0.73$) from that for Tarboro (9.1 ± 0.9). The highest hourly UV_{app} (11) was measured at both sites on July 17, 2019, at 1 PM, while the highest daily mean UV_{app} (6.4) was measured at Tarboro on the same day. Figure 2 shows the daily mean and maximum UV_{app} by monitoring day for both sites, which demonstrates fluctuating index values but shows no significant decreasing or increasing trend from April to August.

Table 4 shows the hourly and daily mean, minimum and maximum UV_{app} by month (April to August) and time of the day (morning, noon, afternoon, and evening). Both the hourly (F = 2.75, $P = 0.03$) and daily (F = 7.73, $P < 0.01$) mean UV_{app} indices were significantly different among the monitored months. The highest hourly (5.8 ± 3.0) and daily (5.8 ± 0.6) mean UV_{app} indices were both recorded in July, while the lowest hourly (5.0 ± 2.6) and daily (5.0 ± 0.3) mean UV_{app} indices were both recorded in April. The hourly mean UV_{app} indices were significantly different (F = 745.60, $P < 0.01$) by time of the day. The evening has the lowest hourly mean UV_{app} (1.9 ± 0.9) followed by morning (3.2 ± 1.2), while afternoon has the highest (7.4 ± 1.9). The highest hourly maximum UV_{app} of 11 was recorded during the afternoon in July.

Comparison of UV_{eff}/TLV-based and UV_{app}-based UV risks

Hourly mean UV_{eff} indices (n = 942) were assigned to a UV risk level using the ACGIH TLV as a basis (as shown in Table 1), and 871 of these UV_{eff} indices had corresponding hourly UV_{app} to which they were paired. Figure 3 shows the percentage of each risk level categories assigned based on UV_{eff}/TLV and on UV_{app} derived from the app. "Extreme risk" was

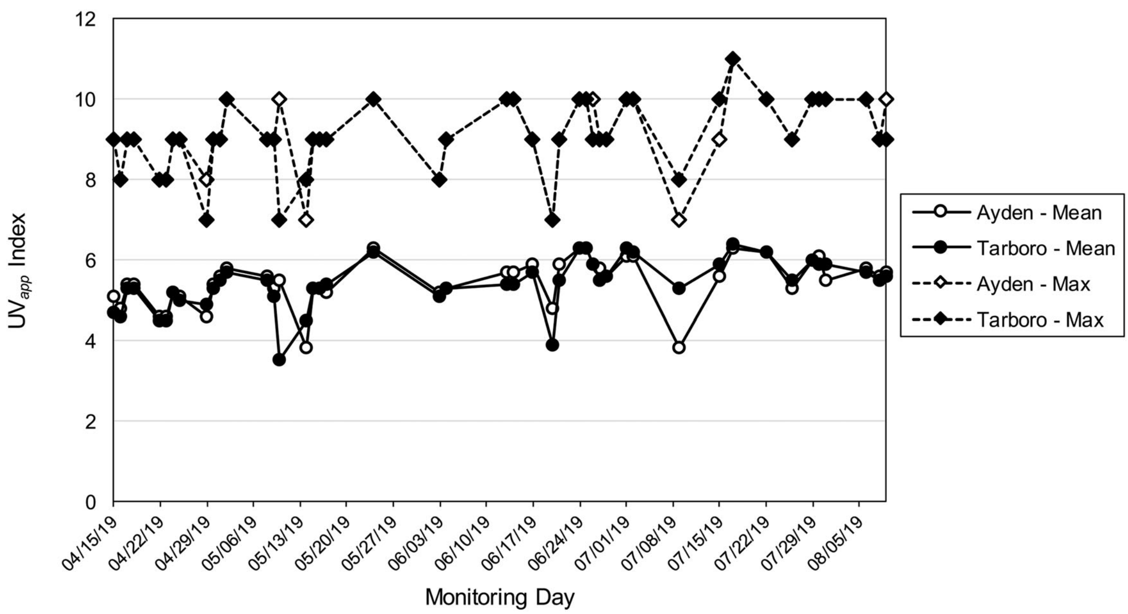

Figure 2. Daily mean and maximum UV_{app} Index by monitoring day and study site.

Table 4. App-obtained hourly and daily mean, minimum and maximum UV Index (UV_{app}) by month and time of day.

		Hourly UV_{app} Index				Daily UV_{app} Index		
Parameter	Hours Monitored (N)	Mean ± SD	Minimum	Maximum	Days Monitored (N)	Mean ± SD	Minimum	Maximum
Month								
April	199	5.0 ± 2.6	1	9	20	5.0 ± 0.3	4.5	5.4
May	200	5.3 ± 2.8	1	10	20	5.3 ± 0.7	3.5	6.3
June	240	5.6 ± 2.8	1	10	24	5.6 ± 0.5	3.9	6.3
July	200	5.8 ± 3.0	1	11	20	5.8 ± 0.6	3.8	6.4
August	60	5.7 ± 3.0	1	10	6	5.7 ± 0.1	5.5	5.8
Time of Day[A]								
Morning	180	3.2 ± 1.2	1	5	—	—	—	—
Noon	180	7.3 ± 1.4	2	10	—	—	—	—
Afternoon	360	7.4 ± 1.9	2	11	—	—	—	—
Evening	179	1.9 ± 0.9	1	3	—	—	—	—
Overall	899	5.4 ± 2.8	1	11	90	5.4 ± 0.6	3.5	6.4

[A]Morning – 8 AM to 11 AM; Noon – 11 AM to 1 PM; Afternoon – 1 PM to 5 PM; Evening – 5 PM to 7 PM

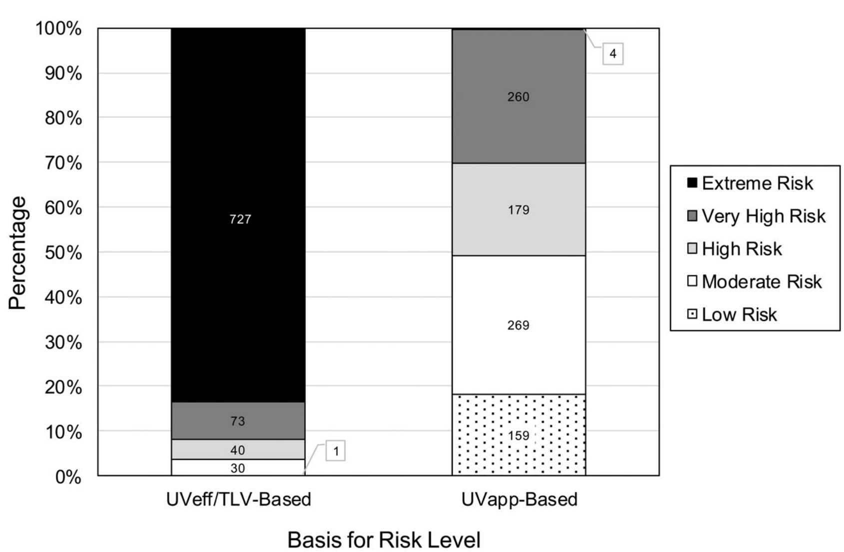

Figure 3. Percentage of assigned UV risk levels (n = 871) for UV_{eff}/TLV-based and UV_{app}-based risk.

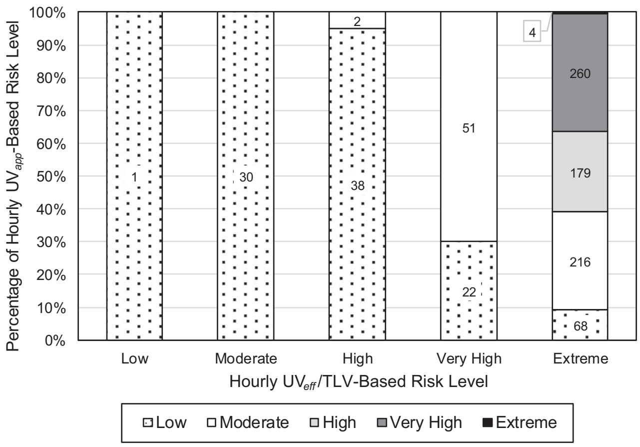

Figure 4. Percentage of hourly UV_{eff}/TLV-based risk level assignments with the same hourly UV_{app}-based risk level assignments.

overwhelmingly the most commonly assigned risk level for UV_{eff} indices (n = 727, 83.5%), followed by "very high risk" (n = 73, 8.4%) and "high risk" (n = 40, 4.6%). In contrast, "moderate risk" was the most common assigned risk level for UV_{app} indices (n = 269, 30.9%), followed by "very high risk" (n = 260, 29.9%) and "high risk" (n = 179, 20.6%). Overall, the UV_{app} had very different percentages for all risk assignments compared to those of the UV_{eff}. For example, the percentage of "extreme risk" assignments based on the UV_{app} (0.5%) is much smaller compared to that based on the UV_{eff} (83.5%), with a difference of 83%.

The reliability of the EPA app in assessing workplace risk to UV exposure was determined by comparing the UV_{app}-based risk levels to the UV_{eff}/TLV-based risk levels obtained from UV monitoring as the "gold standard." Figure 4 shows the percentage of hourly UV_{eff}/TLV-based risk level assignments that had the same hourly UV_{app}-based risk level assignments. There was only one "low risk" assignment based on UV_{eff}, which was also assigned as "low risk" by the app.

Among the UV_{eff}/TLV-based "moderate risk" assignments (n = 30), none was assigned the same risk level but 100% was assigned a lower risk level of "low" by the app, making the app less conservative (i.e., less protective) for "moderate risk" conditions. Similarly, 0% of the UV_{eff}/TLV-based "high risk" (n = 40) and "very high risk" (n = 73) assignments was assigned the same risk level by the app, while 100% were assigned lower risk levels (e.g., 95% and 5% of UV_{eff}/TLV-based "high risk" assignments were identified as "low risk" and "moderate risk", respectively, by the app) (Figure 4). This indicates that the app is even less conservative for "high risk" and "very high risk" conditions.

On the other hand, among the UV_{eff}/TLV-based "extreme risk" assignments (n = 727), 0.6% (n = 4) were also assigned the same risk level of "extreme risk" by the app, while 99.4% (n = 723) were assigned lower risk levels (9.4% as low risk; 29.7% as moderate risk; 24.6% as high risk; 35.8% as very high risk). This indicates that the app is still less conservative in predicting risk levels for "extreme risk" conditions but to a lesser extent compared to "moderate risk", "high risk", and "very high risk" conditions, wherein 100% were assigned lower risk levels. Overall, among all UV_{eff}/TLV-based risk assignments (n = 871), 0.6% (n = 5) were assigned the same risk level by the app, while 99.4% (n = 866) were assigned lower risk levels.

Discussion

The hourly and daily UV_{eff} indices in this study were not significantly different among months, even during cooler months (e.g., April) compared to hotter months (e.g., July). This indicates that the extent of solar UV exposure may not be positively correlated with ambient temperature. Beck et al. (2018) found that WBGT index as heat stress indicator is not a good proxy for UV index during the summer and fall seasons, which can be potentially dangerous when low heat stress conditions are mistakenly assumed to have low UV exposures (i.e., false sense of safety). Although sunlight exposure is expected to be highest during the summer (NIOSH 2018; WHO 2003), UV protection must also be used during the cooler months or seasons. It is also important to recognize that outdoor workers may be at risk of UV exposure even on cloudy days (NIOSH 2018; WHO 2003).

Hourly, UV_{eff} and UV_{app} indices were found to be significantly different by time of day, with the highest mean UV index at noon or afternoon and lowest in the evening. This finding is similar to those in Beck et al. study (2018), wherein the highest mean UV exposure was measured at noon. It is known that solar UV exposure is highest between 10:00 AM and 4:00 PM, increasing the risk of sunburn when working outdoors during these times (NIOSH 2018). Additionally, solar UV exposure at noon is shown to be highest when the solar zenith angle is at a minimum and the solar elevation angle is greatest (Sliney and Wengraitis 2006).

Results from this study indicated excessive UV exposures in agricultural settings in eastern NC at any time of the day during all the monitored months of

April to August, as demonstrated by very high percentages (99.9–100%) of hourly or daily UV_{eff} that exceeded the corresponding TLVs for occupational UV exposure. This finding clearly indicates the need for UV exposure prevention strategies among agricultural workers, regardless of the time of day (morning, noon, afternoon, evening) when sun exposure exists, although with varying degree. It is not unexpected that evening time had the lowest UV exposure, but the hourly TLV was still exceeded 99.4% of the time during this period. A previous study on groundskeepers (Beck et al. 2018) had similar findings and supports the need to implement preventive measures to reduce UV exposure among workers even during the colder months (i.e., April) and times of the day (i.e., morning or evening). Gies and Wright (2003) also demonstrated excessive UV exposures among outdoor workers wherein 90% had UV exposures exceeding occupational UV exposure limits, with 50% exceeding the limits more than four times.

The maximum exposure times (t_{max}) calculated for each hourly mean UV_{eff} ranged from 1.67 min to 1.45 hr. Considering that no calculated t_{max} exceeded 1.45 hr, agricultural workers are generally recommended not to work outdoors for more than 1.5 hr without any protective measures from UV exposure, regardless of the month or time of day. However, noon had the lowest t_{max} (1.7–10.0 min), followed by afternoon (1.7–11.3 min), due to the highest measured UV_{eff} indices during these times of the day. This finding indicates that, without using any protective measures, the length of time working outdoors at noon or afternoon must not exceed around 10 min. CDC (2020) recognizes that solar UV radiation has the potential to damage the skin in as little as 15 min. Moreover, Gies and Wright (2003) found that measured UV indices for outdoor workers exceeded the occupational exposure limits in 6–8 min. Since most of agricultural work may not be possibly accomplished during this very short time period (i.e., within 10 min), it is crucial that protective measures be implemented to reduce UV exposure among agricultural workers during noon to afternoon. In general, it is important that UV risk be considered in all outdoor occupations and that appropriate protective measures and policies be implemented to reduce UV exposures (Modenese et al. 2019). Various protective measures against UV exposure include wearing sunscreen with a minimum of SPF 15, high-SPF clothing, wide-brimmed hats, and wrap-around sunglasses with UV protection, taking breaks in shaded areas, rescheduling outdoor work outside the peak UV radiation period, and employee training (CDC 2020; ICNIRP 2007; NIOSH 2010; Sliney 2001; WHO 2003).

In this study, the reliability of the EPA UV Index app as an occupational risk assessment tool for agricultural settings was assessed by comparing the UV_{app}-derived UV risk levels provided by the app to the UV_{eff}-derived UV risk levels measured onsite by UV radiometers. Overall, the risk assignments from the app were very different from those based on the U_{eff}/TLV criteria and are generally more distributed among risk levels from "low risk" to "very high risk". In contrast, a majority of the UV_{eff}/TLV-based risk assignments was "extreme risk". Comparing by risk level assignment, the app was only reliable in identifying low-risk conditions, wherein the "low risk" assignment based on UV_{eff}/TLV was also assigned as "low risk" by the app. However, the app was shown to be unreliable in assessing more severe risk conditions (i.e., moderate to extreme). For example, none of the UV_{eff}/TLV-based moderate to very high risk assignments and only 0.6% of UV_{eff}/TLV-based extreme risk assignments were also assigned the same risk level by the app. At these risk conditions, 99.4–100% of the UV_{eff}/TLV-based risk assignments were assigned lower risk levels by the app, making the app less conservative (i.e., less protective). Unfortunately, the app being reliable for low risk conditions may have limited use since the greatest concern involves the more dangerous risk levels (e.g., very high risks) wherein serious adverse effects are more likely to occur. Moreover, findings showed that there is approximately 9–100% possibility, depending on the severity of risk conditions, that a "low risk" assignment given by the app may be incorrectly assessing a higher risk condition. It is important to address these findings because it affects the corresponding preventive measures that the workers are recommended to use based on the assigned risk level. For example, at low risk level (i.e., UVI of 1–2), the app states that no protection is needed and that "you can safely stay outside using minimal sun protection" (EPA 2015), which is similar to recommendations from other international health organizations (WHO 2002). This may become potentially hazardous in scenarios wherein a "low risk" assigned by the app implies to the worker that no protection is needed when the UV_{eff}/TLV-based risk level is actually more severe (i.e., moderate to extreme). More information on UV preventive measures must be included in the app for low risk levels (UVI of 1–2), similar to those found in other resources wherein wearing of sunglasses and sunscreen was recommended even at low risk levels, especially if the sun exposure time exceeds an hour (EPA 2004; CCOHS 2016).

Findings in this study demonstrated that the UV risk levels from the app did not correspond well with the UV_{eff}/TLV-based risk level derived from onsite UV measurements. There are several possible reasons for this finding. First, the local conditions used to calculate the UVI at the NOAA regional weather stations used by the app may be different from those at the agricultural sites. The straight-line distances between the agricultural site and weather station for the Tarboro and Ayden locations were 6.8 and 6.3 miles, respectively. Cloud cover and ground elevation, which are used to calculate the ground-level strength of the solar UV radiation, may vary significantly by location and could have contributed to the differences in UV risks between the local worksite and the regional weather station. UVI forecasts were previously found to correlate well with local instrument-derived UV measurements under clear-sky and light-cloud conditions but tend to either under- or overestimate UV under heavy-cloud and rainy conditions (He et al. 2013). Moreover, the UVI values provided by the app are calculated using forecasted stratospheric ozone concentration and forecasted cloud amount for the next day instead of the actual weather conditions at the time of the local UV measurements. Even if the forecast correctly predicts a rainy day, the actual UV measurements can still be potentially high during a break in the cloud cover (He et al. 2013). Thus, onsite UV measurements may provide a more accurate representation of the actual UV exposure of outdoor workers.

Second, the use of the UVI was originally intended for the general public, specifically the vulnerable and highly exposed groups (e.g., children, tourists) (WHO 2002), and not for workers. The UVI was originally developed as an educational tool to increase public awareness on UV health risks and sun protection and to improve the public's attitude and behavior regarding UV exposure (WHO 2002). Although knowledge of the UVI may have some use in determining the level of protective measures for outdoor workers, the UVI is of limited value for this occupational group other than as baseline exposure value for initial training for safe outdoor work practices (ICNIRP 2007). Thus, the UVI may be useful as a general educational or awareness tool but has limitations as an occupational exposure assessment tool.

Limitations

The generalizability of the study findings may be limited to the two agricultural study sites in eastern NC. It is recommended that further studies are conducted in other regions of NC and other states with different local conditions (e.g., higher ground elevation) that may affect ground-level UV exposure. Lastly, the range of UV_{eff} index assigned to risk level categories was arbitrarily based on TLVs for different exposure durations, although the criteria set in this study was deemed reasonable by the authors. A sensitivity analysis is recommended to determine the effects of changing the UV_{eff} index ranges per risk level category on the reliability of the EPA app.

Conclusions

Occupational exposure to solar UV in agricultural settings in eastern NC was found to exceed both hourly and daily (8-hr) ACGIH TLVs based on onsite UV measurements, even during the cooler months or times of the day. UV exposures were found to be highest at noon or afternoon but were not significantly different among monitored months. Findings indicate the importance of using protective measures among agricultural workers regardless of the time of day or year when sun exposure exists, particularly during extended exposure times.

The EPA UV Index app was found to be reliable in identifying low risk conditions, but its reliability decreased as the UV risk condition became more severe. The app was inaccurate in assessing UV risk in occupational outdoor settings with moderate to extreme risk conditions, with 0% to $<1\%$ of the UV_{eff}/TLV-based moderate to extreme risks matching those identified by the app. Given the varying degree of reliability of the app depending on the UV risk conditions, the use of the app to assess occupational risk to UV exposure in agricultural setting is not recommended. The performance of the app in assessing UV risk was shown not to be protective of agricultural workers and potentially other outdoor workers. A means to provide more reliable, readily accessible information on UV risk and protective measures is still needed for use by agricultural workers and other similar outdoor workers.

Acknowledgments

The authors would like to thank the Pitt County Cooperative Extension center for their assistance in identifying and recruiting agricultural sites for the study. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of NIOSH or SCAHIP.

Funding

This study was supported by a pilot grant from the National Institute for Occupational Safety and Health (NIOSH) through the Southeast Center for Agricultural Health and Injury Prevention (SCAHIP).

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