Measured Anatomical Distributions of Solar UVR on Strawberry Production Workers in Italy

G. Nardini, D. Neri, M. Paroncini

ABSTRACT. *The exposure of outdoor workers to solar ultraviolet radiation (UVR) has been known for some time. Measurements of erythemally weighted UVR are usually related to days of exposure and to the anatomical distribution of UVR on the human body. The aim of this research is to describe the UVR exposure of workers during a strawberry production cycle in order to assess the UVR hazard and to identify the highest exposure in the anatomical distribution of UVR on the body during an entire agricultural production cycle. This research was carried out on the experimental farm (Azienda Agraria Didattico-Sperimentale) of Università Politecnica delle Marche in Agugliano, Italy. A spectrometer was used to measure UVR, and electronic dosimeters were used to record UVR exposure. The measurements were carried out on all working days of the strawberry production cycle in 2012 during daily peak UVR levels. The daily UVR exposure geometric mean and the percentage ambient UVR in the strawberry production cycle were calculated and analyzed to assess the hazard for workers during the entire production cycle. The nape of the neck was the anatomical site most exposed to UVR. The mean daily UVR exposure on the nape of the neck was higher than 1.50 SED, the minimum value required to produce perceptible erythema in unacclimatized white skin, and a maximum value of 2.29 SED was measured. Real-time exposure data suggest that it may be useful to remind workers of the risks associated with UVR exposure.*

Keywords. *Erythemal, Exposure, Strawberry, UV, Worker.*

Solar radiation is an important natural factor because it forms the Earth's climate and has a significant influence on the environment. The ultraviolet (UV) part of the solar spectrum plays an important role in many processes in the biosphere. It has several beneficial effects, but it may also be very harmful if the UV exposure exceeds safe limits. If the amount of UV radiation (UVR) is sufficiently high, the self-protection ability of some biological species is exhausted, and the subject may be severely damaged. This also concerns the human organism, in particular the skin and eyes. The adverse effects of sunlight exposure are numerous. Clinical manifestations of acute exposure include sunburn and tanning. Chronic exposure to sunlight results in wrinkling, pigment alterations, and a yellowish, coarse texture of the exposed skin. Chronic exposure may also result in the development of cutaneous malignancies, including basal and squamous

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cell carcinomas and malignant melanoma (Lucas et al., 2006). Immune suppression by UVR was studied in animal models and has been observed in humans. Diffey (2004) studied the relationship between UVR and its subsequent biological effects. Parisi (2005) developed a study of UVR exposure based on the incident-weighted irradiance on a given surface over a specified period of time.

A number of previous studies have measured the solar UVR exposure of outdoor workers (Milon et al., 2007; Moehrle et al., 2003; Vishvakarman et al., 2001). Holman et al. (1983) investigated the proportions of ambient UVR received at several anatomical sites in five occupations and nine outdoor recreational activities. Kimlin et al. (1998) analyzed the effect of human exposure to solar UVR due to occupation (outdoor workers, schoolchildren, and home workers). Cockell et al. (2001) analyzed the UVR exposure of arctic field scientists involved in biological and geological fieldwork. Godar (2005) showed that UV exposure ranges between 5% and 15% of the total ambient UV dose and can reach 20% to 30% for outdoor workers. Diffey (2002) showed that solar UV irradiation depends on the local UV climate, people's behavior, which includes the time spent outdoors, and use of photoprotective agents. Diffey et al. (1996) conducted a study to assess the outdoor UVR exposure of young people in three different regions of England using polysulfone (PS) dosimetry. Boldemann et al. (2004) carried out measurements of children's exposure in two outdoor environments using biotechnical spore dosimeters. Thieden et al. (2005) monitored UVR exposure of Irish and Danish gardeners over a four-month summer period during work and leisure activities by means of diaries and personal electronic dosimeters. Siani et al. (2009) monitored UVR exposure of sunbathers at a Mediterranean Sea site. Gies and Wright (2003) measured the solar radiation exposure of outdoor workers in the construction industry in Queensland, Australia. Hammond et al. (2009) described the patterns of UVR exposure experienced by outdoor workers from selected occupations in New Zealand. Nardini et al. (2012) monitored the UVR exposure of workers during two spring months. However, there seems to be a limited number of studies that specifically examine UVR exposure of agricultural workers in different agricultural activities.

The objective of this study was to analyze and assess the UVR exposure of workers during the strawberry production cycle at an experimental farm in Italy. In this research, solar UVR field measurements of the upper half of the body were collected during the production cycle. This study describes the pattern of occupational solar UVR exposure to help identify its impact and hazard for workers. Exposure to UVR is an occupational health and safety issue for outdoor workers because excessive exposure is associated with negative health outcomes. In this analysis, a complete agricultural production cycle was chosen to study the levels of UVR exposure experienced by field workers.

Materials and Method

Experimental Farm

The investigation of UVR exposure was carried out in 2012 at the experimental farm (Azienda Agraria Didattico-Sperimentale) of Università Politecnica delle Marche. The experimental farm is located in Agugliano (43° 32′ 40″ N, 13° 23′ 25″ E, 195 m above sea level) and was created in 1993 to conduct field research projects on behalf of the Università Politecnica delle Marche. Research activities include breeding, variety evaluation, cultural practices, fertility, and weed, insect, and disease control for grapevines, olive and fruit trees (apple, pear, peach, plum, apricots, and cherry), straw-strawberries, durum wheat, sunflower, barley, corn, sorghum, beans, and chick peas. Strawberry production is of a June-bearing type and includes soil preparation in June; seeding of cold-stored plants in late July and early August on raised beds with plastic mulching; over-plant irrigation for acclimatization in August; irrigation, spray against diseases, and fertilization in August and September; plant cleaning of flowers and runners after planting in August; cleaning of dead leaves after the winter rest in January and February; straw distribution in March and April; and harvest in April or May, depending on the season.

Workers

Six workers at the experimental farm were selected for investigation of UVR exposure on the upper half of the body during the strawberry production cycle. The mean age of the workers was 35; five were female, and one was male. The workers' physical characteristics included dark hair and eyes with fair or medium complexions. Exposure to UVR was measured with personal dosimeters on the upper half of the worker's bodies (forearm, forehead, cheek, and nape of the neck) on work days during agricultural activities. The workers were asked to follow their usual work habits.

Procedures

The incident irradiance on a horizontal surface (W m^{-2}) over a specific period of time was measured using a spectrometer (model CAS 120, Instrument Systems, Munich, Germany). The CAS 120 is equipped with a crossed Czerny-Turner spectrograph and an array detector, and with electronic equipment for data collection and device control. The instrument is controlled by the software provided with it (SpecWin Pro) through a USB interface. The spectral range is 200 to 800 nm, the spectral resolution is 2.7 nm, the data point interval is 0.35 nm, the wavelength accuracy is ±0.3 nm, and the integration time is 4 ms to 20 s.

The incident erythemally weighted irradiance on anatomical sites over a specific period of time (J m^{-2}), called UVR exposure, was measured with personal dosimeters (model X-2000-5, Gigahertz-Optik, Türkenfeld, Germany). The measurement range for UV-A irradiance is 50 nW cm^{-2} to 180 mW cm^{-2} with a maximum resolution of 1 nW cm^{-2}, and the measurement range for UV-B irradiance is 165 nW cm^{-2} to 670 mW cm^{-2} with a maximum resolution of 3.3 nW cm^{-2}. The CIE erythemal action spectrum (CIE, 1987) was considered. Each worker was equipped with personal dosimeters that were secured to the cheek and nape of the neck using an adhesive and to the forehead and forearm using tape, as shown in figure 1.

The UVR exposure values were measured at 30 min intervals from 10:00 a.m. to 12:00 noon (lunch time was from 12:00 noon to 2:00 p.m.) and from 2:00 to 4:00 p.m. local time, for a maximum time interval of 4 h, which was characterized by high UVR levels during 2012. During working hours, the workers were subjected to sunlight. The workers sought shade during their lunch break. The upper body was exposed to a UVR regimen that often changed on second-to-second time scales.

Analysis

All UVR exposures on specific anatomical sites are described in SED units, the recommended unit for expressing personal UVR exposure, where 1 SED = 100 J m^{-2} normalized to 298 nm according to the CIE erythemal action spectrum (CIE, 1987) and

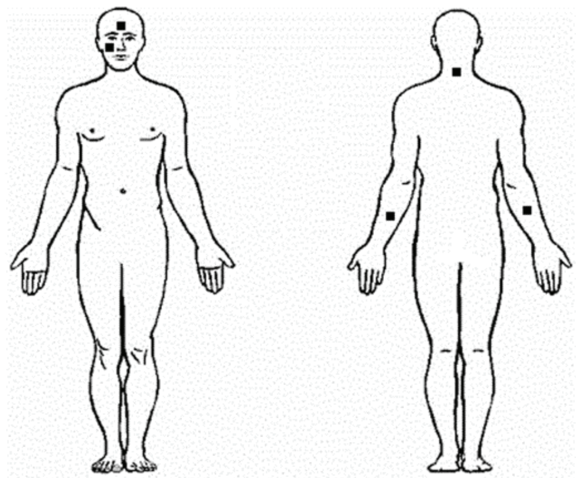

Figure 1. Dosimeter locations on the workers' bodies.

CIE standard erythemal dose (CIE, 1997). An exposure of approximately 1.5 to 3.0 SED is required to produce perceptible erythema in unacclimatized, unprotected white skin.

The daily UVR exposure geometric mean was calculated and analyzed for each activity of the strawberry production cycle. The period of time dedicated to soil preparation and seeding was eight days, the cleaning period was nine days, the fertilization and straw distribution period was five days, the irrigation period was sixteen days, and the harvesting period was nineteen days. During periods not dedicated to activities concerning the strawberry production cycle, the workers devoted their time to other agricultural activities. To reduce the influence of seasonal and weather conditions, the percentage ambient UVR was calculated as the workers' personal UVR for a given time period divided by the concurrent available ambient UVR. Differences in exposure between locations on the upper half of the body were examined to identify the highest exposure at a particular anatomical site to assess the UVR hazard during an entire agricultural production cycle.

Results

The daily personal UVR exposure geometric mean (in SED units) at the four anatomical sites for each activity of the strawberry production cycle and the percentages of the concurrent ambient UVR are shown in tables 1 and 2. The mean UVR exposures at specific anatomical sites represent differences for each activity. The percentage ambient UVR was calculated to reduce the influence of seasonal and weather conditions. The results in the tables were obtained by averaging the results recorded in the different body postures assumed by the workers. The sensors were positioned in such a way as to be in direct sunlight (an effort was made to avoid blocking the sunlight by clothes). As shown in table 1, the daily UVR exposure geometric mean at the forearm, forehead, cheek, and nape of the neck were relevantly different for each activity within the agricultural cycle, with exposure ordered across the seasons as follows: winter < spring < summer.

Figure 2 shows the daily UVR exposure on the forearm, forehead, cheek, and nape of

Table 1. Daily personal UVR exposure geometric mean (SED) for each activity.

	UVR Exposure (SED)			
Strawberry Production Activity	Forearm	Forehead	Cheek	Nape of Neck
1. Soil preparation and seeding	0.48	0.43	0.39	0.85
2. Cleaning	0.90	0.81	0.72	1.61
3. Fertilization and straw distribution	1.00	0.94	0.78	1.94
4. Irrigation and spray	1.24	0.52	0.95	2.29
5. Harvesting	1.07	1.00	0.84	2.01

Table 2. Percentage of ambient UVR (%) for each activity.

	Percentage of Ambient UVR (%)			
Strawberry Production Activity	Forearm	Forehead	Cheek	Nape of Neck
1. Soil preparation and seeding	57.13	51.21	46.46	100.78
2. Cleaning	56.73	50.98	45.66	101.69
3. Fertilization and straw distribution	55.16	51.92	43.34	107.43
4. Irrigation and spray	63.89	27.05	48.75	117.80
5. Harvesting	48.53	45.15	38.12	91.04

the neck. The forearm, forehead, and cheek exposure values were always lower than the values measured on the horizontal plane for each activity. The horizontal plane is a reference value used to better understand the influence of surface albedo and body posture on UVR exposure. In the case of the nape of the neck, the daily UVR exposure is similar to that measured on the horizontal plane for activities 1 and 2, while it is higher for activities 3 and 4 and lower for activity 5. This result is probably due to body posture. The daily UVR exposures on the forearm and forehead are higher than the values measured on the cheek for all activities except activity 4, in which the values measured on the forehead are lower than the values measured on the cheek.

Figure 3 shows the trends in UVR exposure levels at the forearm, forehead, cheek, and nape of the neck during the entire strawberry production cycle. The UVR exposure varied in the range from 3.51 SED, calculated for the forehead during soil preparation and seeding, to 38.23 SED, calculated for the nape of the neck during the harvesting. Figure 4 shows the trends in daily UVR exposure levels per hour at the nape of the neck during the entire strawberry production cycle. The maximum UVR exposure was measured for each activity at around 2:00 p.m., while the minimum value was measured for each activity at 10:00 a.m. Figure 5 shows the trends in percentage ambient UVR levels at the nape of the neck during the strawberry production cycle. The trend for the percentage ambient UVR is very similar for each agricultural activity. The values higher than 100% obtained from 2:00 to 4:00 p.m. are due to ground reflection, body posture, and worker movement.

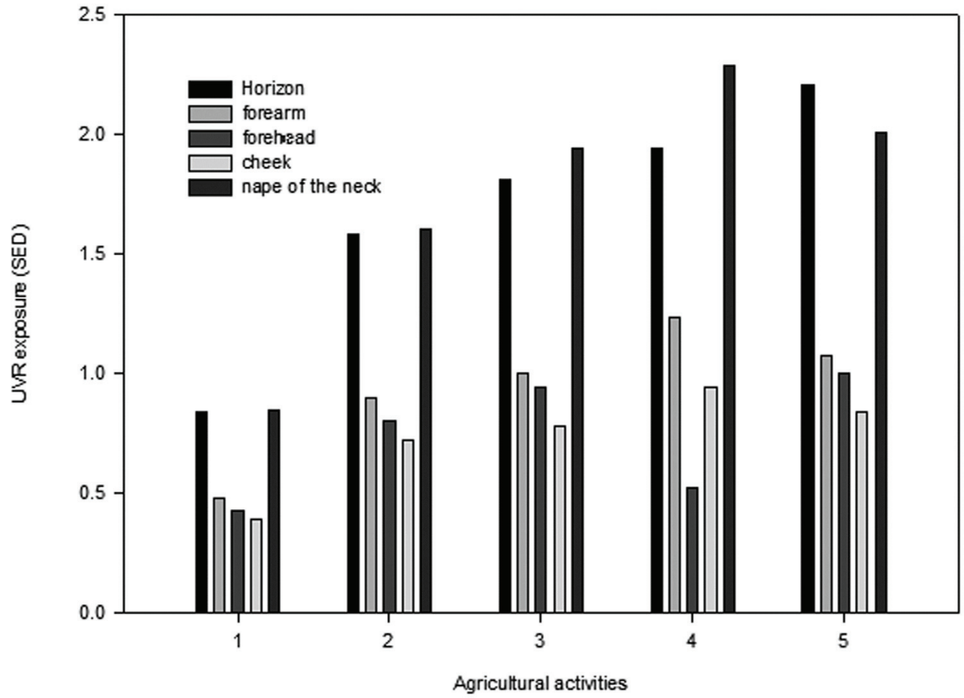

Figure 2. Daily UVR exposure geometric mean at four anatomical sites and on a horizontal plane for all activities of the strawberry production cycle.

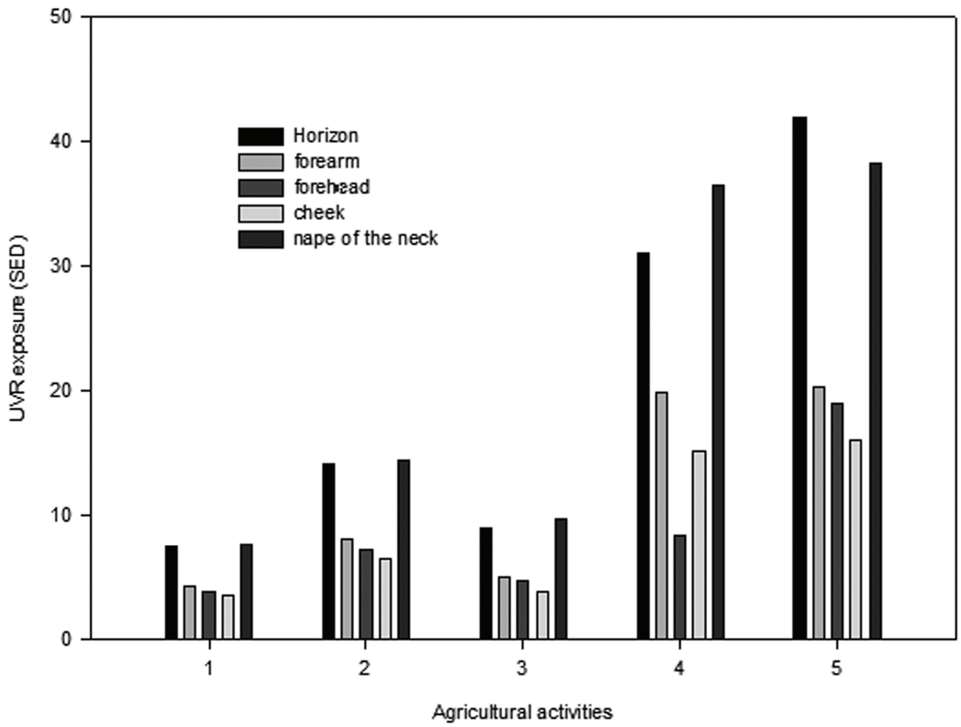

Figure 3. UVR exposure geometric mean at four anatomical sites and on a horizontal plane for all activities of the strawberry production cycle.

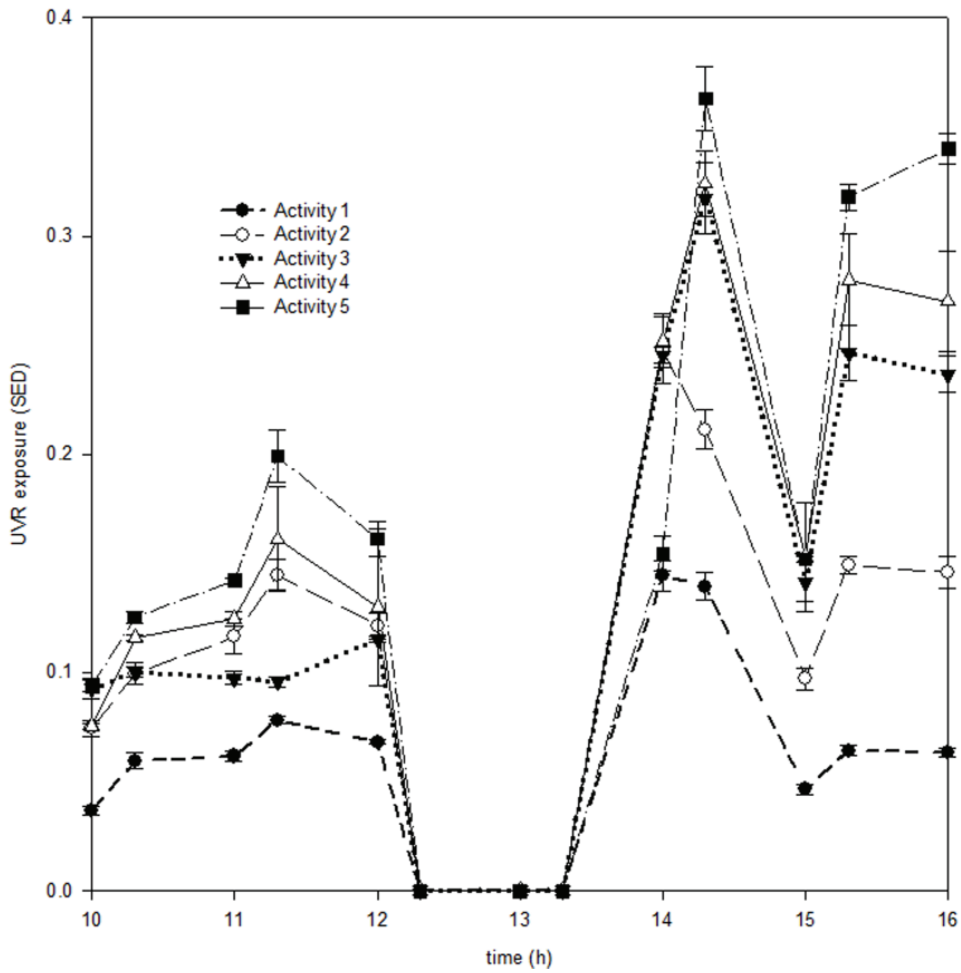

Figure 4. Daily UVR exposure geometric mean per hour at the nape of the neck for all activities.

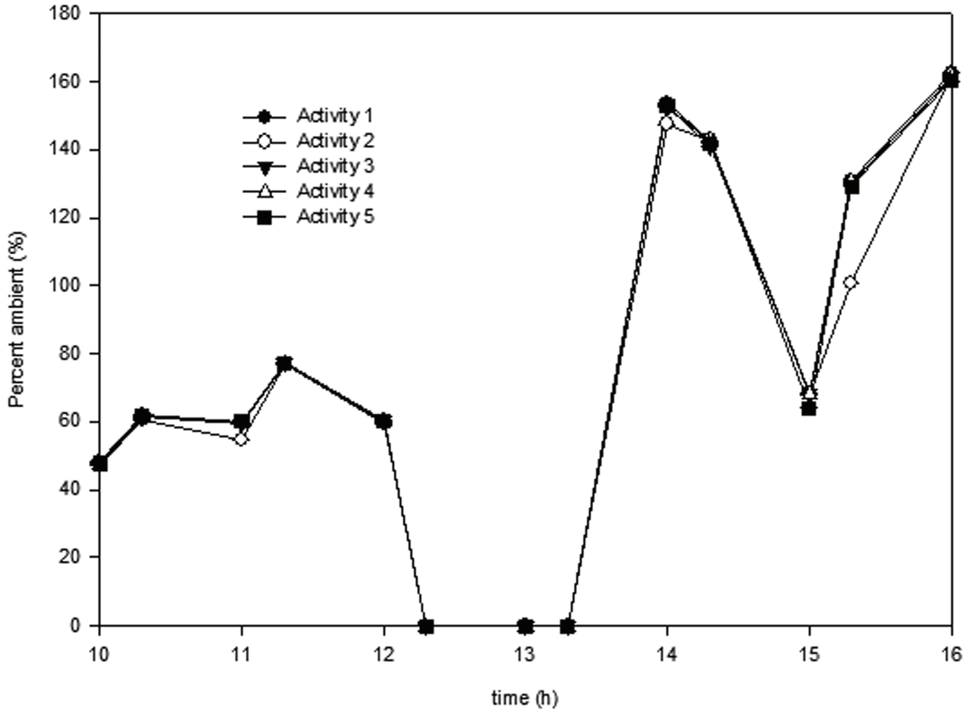

Figure 5. Percentage of ambient UVR at the nape of the neck for all activities.

Discussion

The mean daily UVR exposures at the nape of the neck were higher than 1.50 SED from the spring months to the summer months for cleaning, fertilization and straw distribution, irrigation, and harvesting. The UVR exposures at the other anatomical sites were lower than 1.50 SED during the strawberry production cycle. The highest mean daily UVR exposure was 2.29 SED, which was measured with a corresponding percentage ambient UVR exposure of 117.80%. The calculated percentage ambient UVR value shows that the upper limit reference exceeded 100%; this was presumably due to ground reflection, body posture, and worker movement. The trends in exposure levels at the forearm, forehead, cheek, and nape of the neck were similar to those on the horizontal plane, and during the time of greatest exposure (i.e., the 4 h test period), they all received more than 27.05% of the mean ambient UVR. In particular, the nape of the neck received more than 91.04% of the mean ambient UVR during the 4 h test period with a maximum of 117.80% during irrigation, the cheek received more than 38.12% of the mean ambient UVR with a maximum of 48.75% during irrigation, the forehead received more than 27.05% of the mean ambient UVR with a maximum of 51.21% during soil preparation and seeding, and the forearm received more than 48.53% of the mean ambient UVR with a maximum of 63.89% during irrigation.

The lowest percentage ambient UVR values were obtained for each anatomical site during harvesting, and the highest values were obtained during irrigation, with the exception of the forehead, where the lowest value was for irrigation and the highest value was for harvesting. This result could be due to the orientation of the anatomical site, worker movement, and body posture. During the five activities of the strawberry production cycle, three principal body postures emerged: standing, bending over, and kneeling. The anatomical sites can be placed in descending order of UVR exposure during the agricultural cycle as follows: cheek < forehead < forearm < nape of the neck. The exception was the personal UVR exposure at the forehead during irrigation, which was lower than the exposure measured at the cheek during the same activity. This can be explained by the orientation of the anatomical sites and body movements. The UVR exposure at the nape of the neck showed higher values than the other anatomical sites.

A direct comparison of the results of this study with those of other personal UVR dosimetry studies was not carried out because of differences in study design, such as the anatomical attachment sites of the personal UVR monitors, the measurement duration, and the latitude, altitude, seasons, and weather conditions of the study site.

Real-time exposure data suggest that it may be useful to remind workers of the risks associated with UVR exposure. Using the lunch break to increase personal protection should be emphasized. In addition to advising workers to seek shade during their lunch breaks, the workers should be advised to work in shaded areas when possible during periods characterized by the highest UVR levels. Ideally, for example, workers should reschedule work tasks that involve substantial sun exposure by delaying these tasks until late afternoon. If activities must be carried out during hours when the sun exposure is high, then the workers should wear protective clothing and apply sunscreen to help mitigate the effects of UVR exposure.

The results presented here are for one agricultural production cycle only. This study's main limitations are: investigation of only one agricultural production cycle, a limited period of measurement, a restricted number of working postures, and a small number of workers. Nevertheless, the results provide a first order of magnitude evaluation of the differences in the anatomical distribution of UVR exposure and the differences in UV exposure for different agricultural activities.

Conclusions

The anatomical site most exposed was the nape of the neck. The mean daily UVR exposures at the nape of the neck were higher than 1.50 SED for cleaning, fertilization and distribution of straw, irrigation, and harvesting, with a maximum value of 2.29 SED measured with a correspond percentage ambient UVR exposure of 117.80%. The variation of the daily UVR exposure at the nape of the neck for each activity within the strawberry production cycle showed a maximum value at 2:00 p.m. and a minimum value at 10:00 a.m. An exposure of approximately 1.5 to 3.0 SED is required to produce perceptible erythema in unacclimatized white skin.

The results of this study can potentially be helpful in preventing UVR-related diseases. Thus, they may encourage workers to plan their outdoor activities to prevent excessive UVR exposure, especially to the anatomical sites most exposed, such as the nape of the neck, during the strawberry production cycle. In order to better understand the effects of UVR exposure and its effects on the safety and health of agricultural workers, further research will be carried out for a large number of agricultural production cycles, for each month of the year, for different atmospheric conditions and surface albedos, for different worker postures at this experimental farm, and at other experimental farms in the Marche region with a larger number of workers and different working activities. The biological effects of individual responses to UVR exposure and photosensitivity should also be investigated.

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