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Why do highly polarizing black burnt-up stubble-fields not attract aquatic insects? An exception proving the rule

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Abstract

Horizontal black surfaces are usually very attractive to polarotactic aquatic insects, since they generally reflect highly and horizontally polarized light, and thus imitate water surfaces. We monitored highly polarizing black burnt-up stubble-fields, but surprisingly never found aquatic insects or their carcasses in the ash, although flying polarotactic insects were abundant in the area, which we showed by attracting them to horizontal black plastic sheets. To explain this observation, we measured the reflection–polarization characteristics of burnt-up stubble-fields in the red (650 nm), green (550 nm) and blue (450 nm) parts of the spectrum at three directions of view relative to the solar meridian. We established that (i) the degree of linear polarization p of light reflected from the black ash is high; (ii) p is the higher, the darker the ash; (iii) the direction of polarization of reflected light is nearly horizontal only towards the solar and antisolar meridians, and it is tilted in other directions of view; (iv) the standard deviation of both the degree and the direction of polarization of reflected light is large. The latter two characteristics explain why burnt-up stubble-fields are unattractive to aquatic insects. These results may be important in the study of the wider environmental effects of post-harvest burning.

Keywords: Aquatic insects; Burnt-up stubble-field; Post-harvest burning; Polarization vision; Polarotaxis; Imaging polarimetry; Visual deception; Environmental effects; Visual ecology

1. Introduction

Aquatic insects detect water by means of the horizontal polarization of light reflected from the water surface (Bernáth, Gál, & Horváth, 2004; Horváth & Varjú, 2003; Schwind, 1991, 1995). These polarotactic insects can be attracted to surfaces reflecting horizontally polarized light, such as dry asphalt roads (Kriska, Horváth, & Andrikovics, 1998), oil surfaces (Bernáth, Szedenics, Molnár, Kriska, & Horváth, 2001; Horváth, Bernáth, & Molnár, 1998; Horváth & Zeil, 1996), black plastic sheets (Bernáth et al., 2001) and car-bodies (Kriska, Csabai, Boda, Malik, & Horváth, 2006; Wildermuth & Horváth, 2005), for example. On the basis of these findings the rule has been proposed that all "black anthropogenic products" (BAP), involving artificial surfaces that reflect light with high and horizontal polarization, deceive and lure polarotactic insects (Bernáth et al., 2001).

A typical and unfortunately frequent BAP is a burnt-up stubble-field. On cultivated areas the burning of stubble-fields produces a fatal effect on animals and microorganisms living on the surface and in the uppermost stratum of the soil: both vertebrate and invertebrate animals often die in large numbers as a result of such post-harvest burning. The soil conditions considerably deteriorate because of the alkaline solution of the ash and due to the decrease of the humus content. During burning of a stubble-field the atmosphere is contaminated by a great amount of smoke which can also reach distant places and produce harmful effects. One could

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assume that after the burning a cooled burnt-up stubble-field is not dangerous to animals. However, the black ash layer reflects highly polarized light due to the Umow effect (Horváth & Varjú, 2003; Können, 1985; Umow, 1905): the darker a surface, the higher the degree of linear polarization of light reflected by it. Thus one could expect that the black ash can attract polarotactic aquatic insects in large numbers, like other BAPs do, and these deceived insects can perish *en masse*, as in the case of other BAPs.

Here, we show that fortunately this is not the case. We monitored various black burnt-up stubble-fields, but never found aquatic insects or their carcasses in the ash. To reveal the reasons for this surprising observation, we measured the reflection–polarization characteristics of burnt-up stubble-fields. By monitoring the flying aquatic insects with a horizontal black plastic sheet in the vicinity of burnt-up stubble-fields, we demonstrate that such insects were abundant. We show here that the unattractivness of highly polarizing black burnt-up stubble-fields to polarotactic insects can be explained by the pattern of the direction of polarization of reflected light. Hence burnt-up stubble-fields are an exception proving the above-mentioned rule. Our results may be important in the study of the wider environmental effects of post-harvest burning.

2. Materials and methods

In the warmer months (from April to September) from 1995 to 2005 in every year we performed field experiments in the vicinity of various kinds of Hungarian wetlands (Kunfehértó, 46°23′N, 19°24′E; Balatonszemes, 46°82′N, 17°78′E; Budapest, 47°48′N, 19°17′E; Hortobágy National Park, 47°32′N, 20°55′E). We investigated the polarotactic water detection of insects associated with water (Bernáth et al., 2001; Csabai, Boda, Bernáth, Kriska, & Horváth, 2006; Horváth et al., 1998; Horváth & Varjú, 2003; Kriska et al., 2006, 1998). If a stubble-field has been burnt up in the vicinity, we walked around systematically on the whole field and looked for insect carcasses. In a previous pilot experiment, we established that in the ash cover we were able to find almost all carcasses, the size of which was not smaller than about 5 mm: In a rectangular area of 10 × 10 m of the ash field we spread over 200 black buttons (mimicking the carcasses of black aquatic insects), the diameters of which ranged from 5 to 20 mm (5 mm, 70; 10 mm, 60; 15 mm, 40; 20 mm, 30), and we tested how many of them could be found by the naked eye. We found that all buttons not smaller than 10 mm were found, and about 90% (62) of the smallest (5 mm) buttons could also be found.

The reflection–polarization characteristics of two Hungarian burnt-up stubble-fields were measured on 3 September 2005 at 13:00 h (local summer time = UTC + 2) near Balatonszemes (46°82′N, 17°78′E) and on 30 September 2005 at 14:00 h (UTC + 2) near Kunfehértó (46°23′N, 19°24′E) by videopolarimetry under clear skies in sunshine. The description and explanation of the technique of videopolarimetry were given in detail by Horváth and Varjú (1997). The first measurement was performed three weeks after the burning and the second measurement was done on the next day after the stubble-field has been burnt up. Since the weather was clear and calm (without rain and wind), the black ash layer of both burnt-up stubble-fields covering the ground was still more or less intact when the measurements happened. There were three different directions of view of the polarimeter relative to the solar meridian: (i) towards the solar meridian (SM), (ii) towards the antisolar meridian (ASM), and (iii) perpendicular to the solar meridian (PSM). In all three cases, the elevation angle of the optical axis of the polarimeter was −30° relative to the horizontal. The polarization patterns of the burnt-up stubble-fields were measured in the red (λ_{max} ± half band width = 650 ± 50 nm), green (550 ± 50 nm) and blue (450 ± 50 nm) parts of the spectrum. Since these patterns were practically independent of the wavelength (because the black ash was colourless), we present here only the patterns of one of the burnt-up stubble-fields measured in the green spectral range.

At Balatonszemes flying aquatic insects were monitored by a 2 × 2 m horizontal shiny black plastic sheet placed on the ground at the border of the burnt-up stubble-field positioned at about 150 m from the Tetves patak (creek) and 2 km from the shore of lake Balaton. In a previous pilot experiment, we ascertained that horizontal matt black and white clothes and aluminium foils did not attract aquatic insects. This control experiment demonstrated that the water insects deceived by the black plastic sheet were attracted by the horizontal polarization rather than by the colour and/or intensity of reflected light (Horváth & Varjú, 2003). The investigation was carried out between 13 and 16 h (local summer time = UTC + 2) on 3 September 2005. All insects were collected manually from the test surfaces by capturing them with insect aspirators (smaller insects) or hand-nets (larger insects). The captured insects were preserved in glass vials filled with 70% ethanol and identified later in the laboratory.

3. Results

Fig. 1 shows a stubble-field prior to burning (Fig. 1A) and after burning (Fig. 1B). Although we checked thoroughly 8 burnt-up stubble-fields, we never found any aquatic insects or their carcasses in the ash. From this, we conclude that black burnt-up stubble-fields are unattractive to polarotactic aquatic insects in spite of the high degree of linear polarization of reflected light.

Fig. 2 shows the patterns of the degree of linear polarization p and angle of polarization α of a typical burnt-up stubble-field measured under a clear sky in the green (550 nm) part of the spectrum when the polarimeter viewed towards the solar meridian (SM), antisolar meridian (ASM) and perpendicular to the solar meridian (PSM). Tables 1 and 2 contain the degree of linear polarization p and angle of polarization α of two burnt-up stubble-fields measured in the red (650 nm), green (550 nm) and blue (450 nm) parts of the spectrum.

Fig. 1. A Hungarian stubble-field near Balatonszemes (46°82′N, 17°78′E) prior to burning (A) and after burning (B).

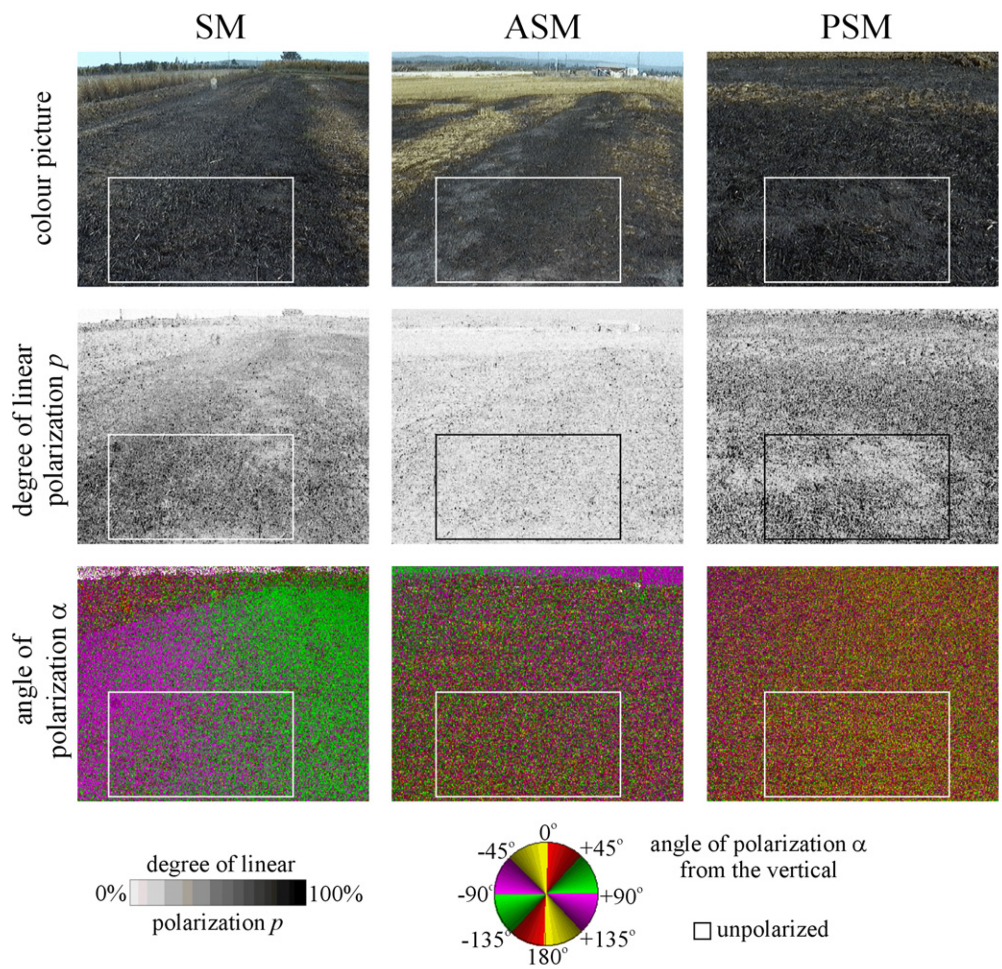

Fig. 2. Colour pictures (1st row), patterns of the degree of linear polarization p (2nd row) and angle of polarization α (3rd row) of the burnt-up stubble-field near Balatonszemes (46° 82′ N, 17° 78′ E) measured by videopolarimetry under a clear sky in sunshine in the green (550 nm) part of the spectrum when the direction of view of the polarimeter was towards the solar meridian (SM, left column), antisolar meridian (ASM, middle column) and perpendicular to the solar meridian (PSM, right column). Angle α is measured from the vertical. The elevation angle of the optical axis of the polarimeter was −30° from the horizontal. The rectangles in the patterns show the areas for which the averages and standard deviations of p and α are given in Table 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this paper.)

Table 1
Degree of linear polarization p and angle of polarization α (average ± standard deviation) of the burnt-up stubble-field near Balatonszemes (46°82′N, 17°78′E) measured in the red (650 ± 50 nm), green (550 ± 50 nm) and blue (450 ± 50 nm) parts of the spectrum for the rectangular areas in Fig. 2 when the direction of view of the polarimeter was towards the solar meridian (SM), antisolar meridian (ASM) and perpendicular to the solar meridian (PSM)

	SM	ASM	PSM
Red (650 nm)			
p (%)	41.3 ± 19.1	16.9 ± 12.4	35.6 ± 22.8
α	91.0° ± 23.0°	90.6° ± 42.8°	118.5° ± 43.8°
Green (550 nm)			
p (%)	40.2 ± 18.7	17.6 ± 12.8	35.1 ± 22.4
α	90.4° ± 23.4°	90.1° ± 42.5°	118.3° ± 43.9°
Blue (450 nm)			
p (%)	39.2 ± 18.7	19.1 ± 13.8	37.1 ± 23.0
α	90.5° ± 25.3°	90.4° ± 42.1°	118.6° ± 43.8°

Angle α is measured from the vertical (vertical, $\alpha = 0°$; horizontal, $\alpha = 90°$).

Table 2
As Table 1 for another burnt-up stubble-field near Kunfehértó (46°23′N, 19°24′E)

	SM	ASM	PSM
Red (650 nm)			
p (%)	39.2 ± 18.6	16.2 ± 13.7	26.8 ± 16.4
α	91.0° ± 18.4°	89.6° ± 41.7°	58.6° ± 29.0°
Green (550 nm)			
p (%)	39.2 ± 18.0	16.8 ± 13.9	26.3 ± 15.9
α	91.6° ± 17.9°	92.6° ± 41.1°	59.0° ± 30.4°
Blue (450 nm)			
p (%)	40.2 ± 18.4	17.7 ± 14.5	27.2 ± 16.7
α	90.7° ± 18.8°	91.2° ± 41.8°	58.6° ± 30.0°

Both p and α are practically independent of the wavelength, because the grey/black ash of burnt-up stubble-fields are colourless. Depending on the direction of view with respect to the solar meridian, the average of p changes from 16.2% to 41.3% with relatively large

Table 3
Aquatic insect species attracted to the horizontal shiny black plastic sheet placed on the ground in the immediate vicinity of a burnt-up stubble-field near Balatonszemes (46°82′N, 17°78′E)

Heteroptera: *Hesperocorixa linnaei*, *Ilyocoris cimicoides*
Coleoptera: *Agabus uliginosus*, *Enochrus quadripunctatus*, *Graptodytes pictus*, *Helophorus brevipalpis*, *Helophorus minutus*, *Hydrochara flavipes*, *Hydroporus angustatus*, *Hydroporus planus*, *Limnebius papposus*, *Ochthebius* sp.

Table 4
Aquatic insect species attracted to the horizontal shiny black plastic sheet placed on the ground in the immediate vicinity of a burnt-up stubble-field during the field experiment performed by Bernáth et al. (2001) near Kunfehértó (46°23′N, 19°24′E)

Ephemeroptera: *Cloeon dipterum*
Coleoptera: *Cybister lateralimargnalis*, *Dytiscus dimidiatus*, *Acilius sulcatus*, *Hydaticus transversalis*, *Rhantus suturalis*, *Copelatus haemorrhoidalis*, *Hyphydrus ovatus*, *Laccophilus poecilus*, *Hydrochara flavipes*, *Hydrochara caraboides*, *Hydrophilus piceus*, *Hydrobius fusipes*, *Spercheus emarginatus*, *Berosus luridus*, *Cymbiodyta marginella*, *Anacaena limbata*, *Enochrus bicolor*
Heteroptera: *Cymatia rogenhofferi*, *Sigara lateralis*, *Sigara striata*, *Sigara falleni*, *Sigara assimilis*, *Hesperocorixa linnaei*, *Corixa affinis*, *Notonecta glauca*

standard deviations ranging from 12.4% to 23%. p is highest (39.2–41.3%) towards the SM, lower (26.3–37.1%) perpendicular to the SM, and lowest (16.2–19.1%) towards the ASM. The direction of polarization of light reflected from burnt-up stubble-fields is nearly horizontally polarized ($89.6° < \alpha < 92.6°$) towards the SM and ASM, but perpendicular to the SM it is not horizontal ($58.6° < \alpha < 118.5°$). The standard deviation of the angle of polarization α is high, ranging from 17.9° to 43.9°. All these polarization characteristics can be clearly seen in Fig. 2. We therefore conclude that burnt-up stubble-fields can be attractive to water-seeking flying polarotactic aquatic insects only from directions of view towards the SM and ASM, where the light reflected from stubble-fields is on average horizontally polarized. From other directions of view, the burnt-up stubble-fields cannot be attractive to flying aquatic insects, because there the direction of polarization of reflected light is not horizontal. Since the first polarimetric measurement happened three weeks after the stubble-field has been burnt up, we conclude that these reflection–polarization characteristics of ash fields can be stable over several weeks.

Tables 3 and 4 show the aquatic insect species caught by horizontal black plastic sheets in the immediate vicinity of two burnt-up stubble-fields. From our insect monitoring, we conclude that there was a diverse community of flying aquatic insects in the air near/above the burnt-up stubble-fields. Consequently, the lack of aquatic insects and their carcasses on the highly polarizing black ash-covered ground cannot be explained by the hypothesis that water-seeking flying insects were absent from the area.

4. Discussion

On the basis of numerous earlier investigations (Bernáth et al., 2004, 2001; Horváth et al., 1998; Horváth & Varjú, 2003; Horváth & Zeil, 1996; Kriska et al., 2006, 1998; Schwind, 1991, 1995; Wildermuth & Horváth, 2005) it was a logical hypothesis that highly polarizing black burnt-up stubble-fields are also attractive to flying polarotactic aquatic insects. However, we experienced frequently in the field the opposite, namely the black ash-covered ground in different Hungarian wetlands was unattractive to aquatic insects in spite of the high degree of linear polarization of reflected light.

The trivial explanation of this finding could be that there were no flying aquatic insects at the observed burnt-up stubble-fields. However, with monitoring the flying aquatic insects near some burnt-up stubble-fields we demonstrated (Tables 3 and 4) that this was not the case: in the vicinity of the observed burnt-up stubble-fields there were always smaller or larger lakes, and the horizontal shiny black plastic sheets placed on the ground in the vicinity of the black ash-covered ground attracted many different aquatic insect species. Hence, there were many flying aquatic insects at the observed burnt-up stubble-fields. In spite of this, we never observed any aquatic insect landing in the black ash, nor found any insect carcass. Although, we were able to detect only larger (>5 mm) insects, it is unlikely that black ash fields would be attractive only to smaller (<5 mm) aquatic insects. In our earlier field experiments (Bernáth et al., 2001; Csabai et al., 2006; Horváth et al., 1998; Horváth & Varjú, 2003; Kriska et al., 2006, 1998) aquatic insects of all sizes turned out to be polarotactic. From this, it is pertinent to conclude that burnt-up stubble-fields are an exception proving the rule: they are ”black anthropogenic products” which are unattractive to polarotactic aquatic insects.

The darkness of the ash of burnt-up stubble-fields can change from dark grey to black. According to the rule of Umow (1905), the darker the ash, the higher the degree of linear polarization p of reflected light. This is clearly seen in Fig. 2 if we compare the p-patterns with the corresponding colour pictures. The relatively high standard deviation of p of light reflected from burnt-up stubble-fields can be explained by the large spatial change of the darkness of the ash. Consequently, the highly polarizing dark ash layer could be attractive to polarotactic aquatic insects, because the higher the p of reflected light, the stronger the attractiveness (Horváth & Varjú, 2003; Schwind, 1991, 1995).

The unattractiveness of burnt-up stubble-fields to aquatic insects can be explained by the characteristics of the pattern of the direction of polarization of light reflected from the ash: the ash layer is a rough surface due to the random orientation of the charred stalks of straw. Rough surfaces possess the characteristic that the direction of polarization of reflected light is always perpendicular to the plane of reflection (Horváth & Varjú, 2003; Können, 1985). In the case of sunlit burnt-up stubble-fields the plane of reflection passes through the observer, the sun and the point of the ash observed. This plane of reflection is vertical towards both the solar meridian (SM) and antisolar meridian (ASM), and it is tilted for other directions of view. This is the reason for our findings that the average direction of polarization of light reflected from burnt-up stubble-fields is nearly horizontal towards the SM and ASM, and it is tilted in all other directions of view (Tables 1 and 2, Fig. 2). The reason for the large standard deviation of the direction of polarization of ash-reflected light is the random orientation of the charred stalks of straw.

We have seen that black burnt-up stubble-fields reflect on average horizontally polarized light in directions of view towards the solar and the antisolar meridian. Since horizontal is the direction of polarization *per se* that attracts aquatic insects, this could lead to a reduced number of insects being attracted to these fields, but not to a complete absence, as we have found. Note, however, that the standard deviation of the angle of polarization α ranges from $\pm 17.9°$ to $\pm 42.8°$ (Tables 1 and 2) toward the solar and antisolar meridians. These deviations of α from the average horizontal direction are large enough to explain why aquatic insects are not attracted to burnt-up stubble-fields even in directions of view parallel to the solar and antisolar meridians.

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