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Light-trap catch of cotton bollworm, *Helicoverpa armigera* in connection with the moon phases and geomagnetic H-index

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Abstract

This study addresses the question whether to what extent (if any) light-trap catch of the harmful pest, *Helicoverpa armigera* (Hübner, 1805) (Lepidoptera: Noctuidae) depends on the Moon phases and the geomagnetic horizontal component (H-index). Therefore, daily relative catch data were assigned to the daily values of geomagnetic field above 0.2125^{-10} T (H-index). We correlated the daily catch results to the daily values of geometric H-index. The numbers of specimens caught and classified according to generation were calculated relative to catch values. Relative catch data were divided according to the Moon phase angle around the four Moon quarters. The relative daily catch data were assigned to the daily values of geomagnetic H-index. We correlated the daily catch results to the daily values of geometric H-index in four moon phases. More abundant catch corresponded to higher H-index values in the New Moon period. Approaching Full Moon led to increasing catch correlating to low H-index value, but there decreasing catch coincided with higher H-index values. There was also decreasing catch at the increasing H-index values in the First Quarter and Last Quarter period. The light trap catch of the *H. armigera* was seemingly influenced by both the moon phases and the horizontal component of geomagnetism.

Keywords Cotton bollworm · Geomagnetism · *Helicoverpa armigera* · Light-trap · Moon phases

Introduction

Helicoverpa armigera (Hübner, 1805) is one of the most dangerous insect pests in the world. In Europe it causes substantial losses to maize, legume, fibre, cereal oilseed and vegetable crops (Romeis and Shanower 1996). Its original distribution area covers tropical and, subtropical regions (Drake and Gatehouse 1995; Scott et al. 2005). The species used to be recorded in Central Europe, even in larger numbers in every 16th or 17th year, due to a possible major outbreak in its primary distribution area (Farrow and Daly 1987). It is considered to be a facultative migrant, emigrating in response to a deterioration of its local environmental conditions for adult survival and larval development. It flies well to light and therefore it can be trapped using a light-trap (Maelzer and Zalucki 1999). Light-trap information is most important from the angle of the determination of the optimal time for protection of crop, but it can supply some additional ecological data as well (Dömötör et al. 2007).

It has long been known (Becker 1964; Kirschvink 1983; Wehner 1984, 1992; Jahn 1986) that insects sense geomagnetic/magnetic fields and they have ability to use it for spatial orientation. Mletzko (1969) placed some ground beetle (*Broscus cephalotes* L., 1758, *Carabus nemoralis* Müller, 1764 and *Pterostichus vulgaris* L., 1758) specimen on in the middle of a 100 square meter asphalt-wainscoted surface in the Moscow Botanic Garden. The beetles flew in a given direction with a precision of +5° at daylight and ± 60° at night. According to this author, the beetles' orientation is controlled by geomagnetism. Iso-Iivari and Koponen (1976) examined the effect of geomagnetism on light-trapping in the northernmost region of Finland. They used the K index values estimated in every three hours, as well as the ΣK and the δH values. A significant correlation was found between the geomagnetic parameters and the number of specimens of the various orders of observed beetles.

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Shimoda and Honda (2013) revealed a correlation between the C and ΣK values and the number of insects caught. In a later study of Pristavko and Karasov (1980) established that at the time of magnetic storms ΣK has a greater influence on the flying activity of the above species. Studying the termite species *Heterotermes indicola* (Wasmann, 1902) Becker and Gerisch (1981) found a stronger correlation between this activity and the vertical component of geomagnetism (Z) than between that and the values of the K index. Tshernyshev (1972) has discussed in a series of studies the results of his laboratory as to light-trapping experiments performed with species of different orders of insects to seek a potential connection between geomagnetism and certain life phenomena. Martin et al. (1989) found that the number of light-trapped beetles and bugs rose many times in the duration of geomagnetic storms in Turkmenia. He found a highly positive correlation between the horizontal component and the number of trapped insects. In addition, this survey found that the number of light-trapped insects significantly rose at the time of magnetic perturbations. Later, however, he reported that while light-trap catches of some Coleoptera and Lepidoptera species increased, that of other Lepidoptera and Diptera species declined during magnetic perturbations (Tshernyshev 1972).

Tshernyshev and Danthanarayana (1998) used an infrared actograph to study the activity of *H. armigera*, a native noctuid (*Helicoverpa punctigera* Wallengren, 1860), and ruby quaker moth under laboratory conditions ruby quaker moth (*Orthosia rubescens* Walker, 1865). Examining the influence of the geomagnetic K index also in the context of the four typical lunar quarters (First Quarter, Full Moon, Last Quarter and New Moon), a significant negative correlation was found in the Last Quarter and a positive correlation in the other three ones. Moths are also disturbed by geomagnetic perturbations. 30 h after perturbations the influence was still discernible.

Examinations over the last decade**s** have also confirmed that some Lepidoptera species, such as large yellow underwing *(Noctua pronuba* L., 1758) heart and dart moth (*Agrotis exclamationis* L., 1758) are guided by both the Moon and geomagnetism in their orientation, and they are even capable of integrating these two sources of information (Baker and Mather 1982; Baker 1987). At cloudy nights, the imagoes of large yellow underwing orientate with the help of geomagnetism (Baker and Mather 1982). Also in this case, their preference lay with the direction they had chosen when getting their orientation by the Moon and the stars. Using hourly data from the material of the Kecskemét fractionating light-trap, we have examined the light trapping of turnip moth *(Agrotis segetum* Denis et Schiffermüller, 1775), heart and dart moth and fall webworm *(Hyphantria cunea* Drury, 1773) in relationship with the horizontal component of the geomagnetic field strength (Kiss et al. 1981).

According to the authors of more recent publications (Srygley and Oliveira 2001; Samia et al. 2010) the orientation/navigation of moths at night may be governed by the Moon or other celestial light sources, but many other phenomena such as geomagnetism may also play a role.

We had stated in our earlier work (Kiss et al. 1981) that the impact of geomagnetism on light-trap catches should be studied with consideration to the prevalent illumination conditions. In our current work we studied the effectiveness of light-trap catches of *H. armigera* in connection with the Moon phases and the horizontal component of geomagnetic field strength.

Materials and methods

The average field strength of the Earth as a magnetic dipole is 33.000γ [$1\gamma = 10^{-5}$ G = 10^{-9} Tesla = 1 nanotesla (nT)]. Geophysical literature (British Geophysical Survey 2018) uses γ as a unit.

The three-hour index Ap and the daily indices Ap, Cp and $C9$ are directly related to the Kp index (Ivory 1997). In order to obtain a linear scale from Kp, (Bartels 1957) constructed the following table to derive a three-hour equivalent range, named Ap index. This Ap index is composed in such a way that at a station at approximately 50 degrees dipole latitude, ap may be regarded as the range of the more disturbed of the two horizontal field components, expressed in the unit of 2nT. The daily index Ap is obtained by averaging the eight values of Ap for each day.

In order to replace the somewhat subjective index Ci, the Cp index - the planetary daily character figure - was developed. Cp is a qualitative estimate of the overall level of magnetic activity for the day determined from the daily sum of eight Ap amplitudes. Cp ranges, in increments of one-tenth, from 0 (quiet) to 2.5 (disturbed). Another index devised to express geomagnetic activity on the basis of the Cp index is the $C9$ index. It converts the 0 to 2.5 range of Cp to one digit between 0 and 9. The simplest local characteristic of magnetic activity is the character number: C_i. The C_p planetary number of characters can be calculated for the total Earth from these numbers based on a few selected observation locations distributed evenly on the Earth (British Geological Survey 2018).

The three-hour K index shows the activity of the variations created by the solar wind, which is measured in every 3 h at all observatories. The K index may be a whole number from 0 up to 9 (Völgyesi 2002). Data on the field strength changes of the horizontal geomagnetic component are given for each 3-h-period in a scale from 0 to 9, where the scale unit is $7\gamma = 7$ nanotesla (nT). The scale is linear (Nowinszky and Tóth 1987).

In our earlier study (Kiss et al. 1981) a correlation was found between the summarized values of horizontal component (values of H-index over 2.150 nT) change of the geomagnetic field-strength measured at night, and the amount of light-trap catches of *H. cunea*. It was stated that the change of
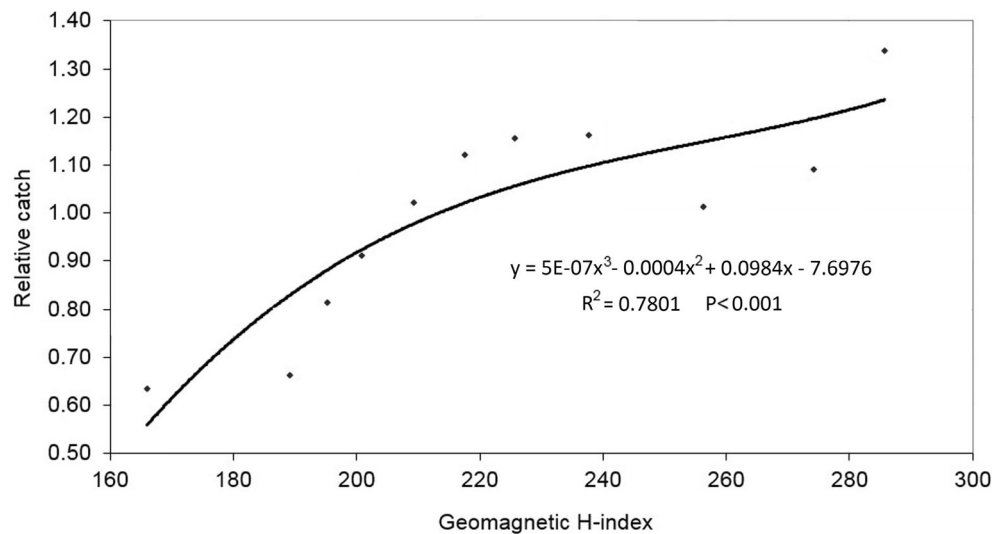
geomagnetic field strength significantly, but in the various moon phases differently influences the catches.

For our present work we downloaded the Earth's magnetic x and y data from the World Data Centre for geomagnetism, Kyoto's website (http://wdc.kugi.kyoto-u.ac.jp/hyplt/). These values were calculated on the horizontal component of the formula, according to the advice of László Szabados (Tihany Geophysical Observatory):

$$H = \sqrt{x2 + y2}$$

In our study we used the data pertaining to *H. armigera* from the material of the Hungarian national light-trap network in the years 1993–2011. There are Jermy-type light-traps used in this network (Jermy 1961). The light source of traps was 100 W normal bulb at 2 m height above ground level. We used chloroform as killing material. In this period, there were successful trapping at 2878 nights and the 55 traps caught 25,531 specimens altogether (between 1993 and 2003). The number of observation data was 6754, because more traps were in operation during one night. Observing data refer to the catching of one trap during one night, regardless of the number of insects caught. The number of observing data exceeds that of the nights because more light-traps worked nights. By observation data, we mean the catch of a species at one night at one observation spot, regardless of the number of specimens, but those nights during which trapping was unsuccessful were not considered.

The number of individuals of a given species caught at different places and in different observation years varies. The collection efficiency of the modifying factors (temperature, wind, moonlight) are not the same at the locations and at the time of trapping, so it is easy to realise that the same number of items captured at two different observation places or time represents different proportion to the test species mass. To circumvent this problem, the introduction of the concept of relative catch was used decades ago. The relative catch (RC) is
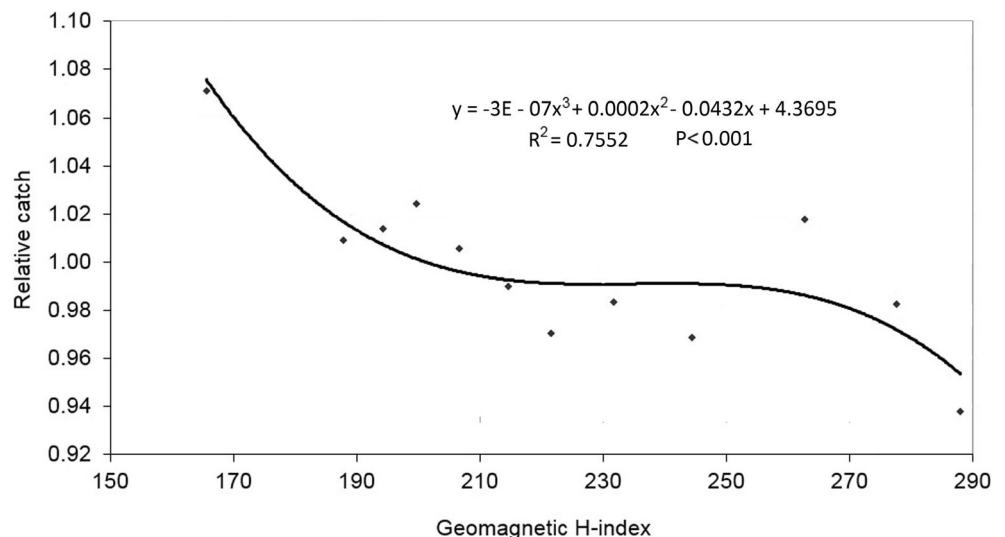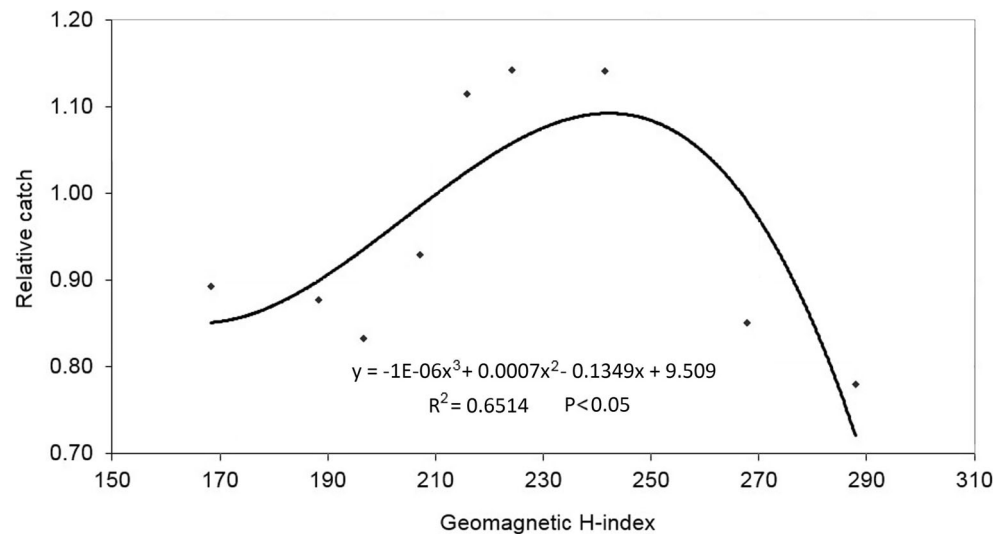
Fig. 3 Light-trap catch of
H. armigera in connection with
the geomagnetic H-index,
Hungarian light-trap network,
1993–2011 (in the vicinity of Full
Moon)

The equation shown in Fig. 3:

$$y = -1E\text{-}06x^3 + 0.0007x^2 - 0.1349x + 9.509$$
$$R^2 = 0.6514 \quad P < 0.05$$

expressed by taking account of a given sampling time unit (in our case, one night). The average number of individuals per unit time of sampling and the number of generations divided by the influence number of the individuals. If the number of specimens taken from the average is the same, the relative value of catch is: 1 (Nowinszky 2003).

We divided our relative catch data to those gained in or in the absence of moonlight and within these two classes established sub-categories according to the Moon phase angle around the four Moon quarters in the following way: in the swarming period of the various species we calculated the value of the Moon phase angle for the 24th hour (UT) of each night. Subsequently, we formed 30 groups of phase angles of the 360 phase angle values of the complete lunar month. The group containing the phase angle values found in the vicinity of a Full Moon (0° or 360°) + 6° is marked: 0. Proceeding from here through the First Quarter in the direction of the New Moon, the groups were marked as: −1, −2, −3, −4, −5,

−6, −7, −8, −9, −10, −11, −12, −13 and − 14. From the Full Moon through the Last Quarter in the direction of the new Moon the groups were: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14. The group of phases containing the New Moon is marked: + 15. Each group contains 12-phase angle values. The four typical Moon quarters contain the following phase angle groups: Full Moon (−2 — +2), Last Quarter (+3 — +9), New Moon (+10 — -10) and First Quarter (−9 — -3).

From the collection data of the examined species the relative catch values (RC) were calculated according to the swarming of examined species. The data were subsequently arranged on the basis of the H-index and assigned to four Moon phases.

Relative catch values were calculated according to the features of the given day, prior to RC values being summed up and averaged. The data were plotted and regression equations were calculated for relative catches of examined species and H-index data pairs in four Moon phases. The regression equations and the significance levels were also determined.

Fig. 4 Light-trap catch of
H. armigera in connection with
the geomagnetic H-index,
Hungarian light-trap network,
1993–2011 (in the vicinity of Last
Quarter)

The equation shown in Fig. 4:

$$y = -1E - 06x^3 + 0.0011x^2 - 0.2707x + 23.539$$
$$R^2 = 0.9427 \quad P < 0.001$$
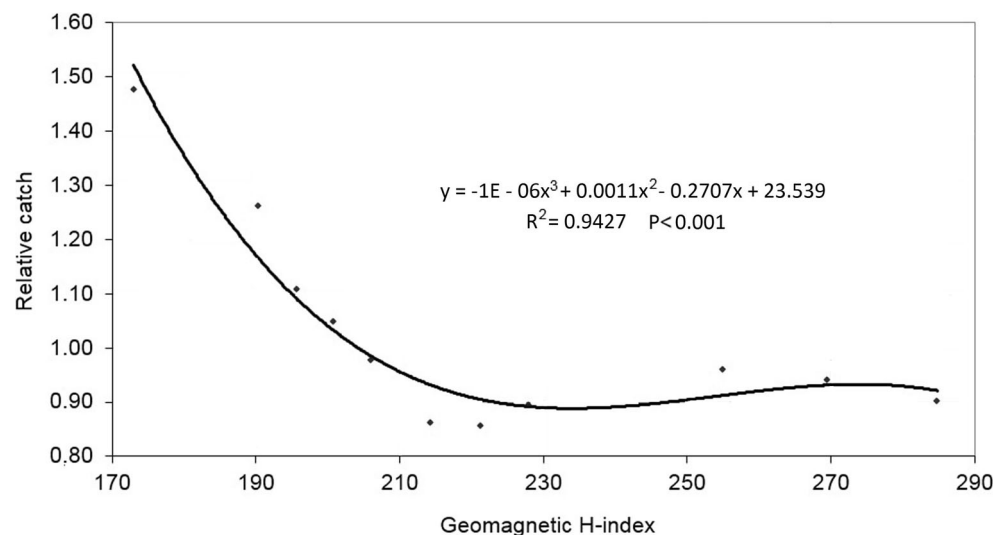
Results and discussion

Light-trap catches of *H. armigera* in connection with the geo-magnetic H-index, Hungarian light-trap network, 1993–2011 as a function of the Moon phases are shown in Figs. 1, 2, 3 and 4. The results of our calculations have shown that in the period of the New Moon when there is no measurable moonlight, the higher values of the horizontal component are accompanied by an increasing relative catch. In the First Quarter and the Last Quarter, growing values of the horizontal component are accompanied by a decreasing catch.

The catching peak of ten harmful Microlepidoptera species is in the First Quarter, while another ten species have the peak in the First Quarter and in the Last one, and only in two cases the peak is in the Last Quarter (Nowinszky and Puskás 2013). This observation in these Moon Quarters is attributed to the highly polarized moonlight. This confirms the results of previous studies (Nowinszky et al. 1979, 2010; Danthanarayana and Dashper 1986; Nowinszky 2004, 2008; Nowinszky and Puskás 2010, 2011, 2012) which have al-ready established that the polarized moonlight helps the ori-entation of insects.

The catches of winter moth (*Operophtera brumata* L., 1758) were the greatest in the First and the Last Quarters. The most probable explanation for this is that the proportion of polarized moonlight in the different lunar quarters varies, with the catches being highest when the proportion is the greatest (Nowinszky et al. 2012a). The study of Nowinszky et al. (2012b) was the first one demonstrating the effect of increasing polarized moonlight in the First and Last Quarter on the increasing flying activity of five caddisfly species.

The proportion of polarized moonlight led to the increase in the catch of *Lygus* sp. (Hemiptera: Miridae) both in the First quarter and the Last Quarter of the Moon (Nowinszky and Puskás 2014).

When Nowinszky et al. (2015) used pheromone traps; in-sects did not fly to a light source, so moonlight does not modify either the catching distance or flight activity. However, at high levels of polarized moonlight, pheromone trap catches will increase, as in the case of light-trap catches of eight harmful Microlepidoptera species.

With the Full Moon approaching at increasing H-index values the catches increase followed by a decrease.

At full moon, the moonlight is not polarized, but in an interval of ±2.5 days, the polarization plane turns over from positive to negative (Nowinszky et al. 1979).

However, this fact does not explain the behavior of these moths in Full Moon. Further research is necessary to find the reason behind this behavior.

It appears that in the period of lunation in which the pres-ence of the Moon provides insects with orientation informa-tion at some time of the night, orientation is guided primarily by light stimulus even if the Moon is not over the horizon.

Increasing geomagnetic field strength may lead to the intensi-fication of the flying activity of insects, collecting is even more effective. On the other hand, approaching the New Moon when insects cannot base their orientation on the Moon at nights, it is presumable that intensifying geomagnetic field strength that increases the security of the orientation of insects will, as against light stimuli, receive an increasingly important role in the process of orientation (Nowinszky 2003).

However, since this topic has been studied only by a few researchers, it would be absolutely necessary to conduct fur-ther research to verify or disprove our hypothesis.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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References

Baker RR (1987) Integrated use of moon and magnetic compasses by the heart-and-dart moth, *Agrotis exclamationis*. Anim Behav 35:94–101. https://doi.org/10.1016/S0003-3472(87)80214-2

Baker RR, Mather JG (1982) Magnetic compass sense in the large yellow underwing moth, *Noctua pronuba* L. Anim Behav 30:543–548. https://doi.org/10.1016/S0003-3472(82)80067-5

Bartels J (1957) The technique of scaling indices K and Q of geomagnetic activity. Ann Int Geophys 4:215–226

Becker G (1964) Reaction of insects on magnetic fields. electric fields and atmospherics J Appl Entomol 54:75–88. https://doi.org/10.1111/j.1439-0418.1964.tb02917.x

Becker G, Gerisch W (1981) Geomagnetobiological rhythms of termite feeding activity and related rhythms. J Interdiscipl Cycle Res 12:247–256. https://doi.org/10.1111/j.1439-0418.1973.tb02301.x

British Geophysical Survey (2018). Geomagnetism. Data and services. http://www.geomag.bgs.ac.uk/data_service/home.html. Accessed 10 Oct 2018

Danthanarayana W, Dashper S (1986) Response of some night-flying insects to polarized light. In: Danthanarayana W (ed) Insect flight: dispersal and migration. 1st ed. Berlin-Heidelberg. Springer-Verlag, Germany, pp 120–127

Dömötör I, Kiss J, Szőcs G (2007) First results on synchrony between seasonal pattern of pheromone trap captures of cotton bollworm,

Helicoverpa armigera and appearance of freshly emerged larvae on developing cobs of corn hybrids. J Pest Sci 80:183–189. https://doi.org/10.1007/s10340-007-0164-y

Drake VA, Gatehouse AG (1995) Insect migration. Tracking resources through space and time. Cambridge University Press, Cambridge

Farrow RA, Daly JC (1987) Long-range movements as an strategy in the genus *Heliothis* (Lep.: Noctuidae); a review of its occurrence and detection in four pest species. Aust J Zool 35:1–24. https://doi.org/10.1071/ZO9870001

Iso-Iivari L, Koponen S (1976) Insect catches by light trap compared with geomagnetic and weather factors in subarctis Lapland. Rep Kevo Subarct Res Stat 13:33–35

Ivory K (1997) Geomagnetic *ap*, *Ap*, *Cp*, and *C9* Indices. http://wwwuser.gwdg.de/~rhennin/ap.html. Accessed 10 October 2018

Jahn E (1986) Physical power zones and insects. A review. J Pest Sci 59:8–14

Jermy T (1961) Investigation of the swarming of harmful insects using light-traps. A Növényvédelem Időszerű Kérdései 2:53–61 (in Hungarian)

Kirschvink JL (1983) Biomagnetic geomagnetism. Rev Geophys 21:672–675. https://doi.org/10.1029/RG021i003p00672

Kiss M, Ekk I, Gy T, Szabó S, Nowinszky L (1981) Common effect of geomagnetism and change of moon phases on light-trap catches of fall webworm moth *(Hyphantria cunea* Drury). J Appl Entomol 91:403–411. https://doi.org/10.1111/j.1439-0418.1981.tb04496.x

Maelzer DA, Zalucki MP (1999) Analysis of long-term light-trap data for *Helicoverpa* spp. (Lepidoptera: Noctuidae) in Australia: the effect of climate and crop host plants. Bull Entomol Res 89:455–463. https://doi.org/10.1017/S0007485399000590

Martin H, Korall H, Förster B (1989) Magnetic field effects on activity and ageing in honeybees. J Comp Physiol A 164:423–431. https://doi.org/10.1007/BF00610436

Mletzko GG (1969) Orientation rhythm at Carabidae. Z Obsh Biol 30:232–233

Nowinszky L (2003) The handbook of light trapping, 1st edn. Savaria University Press, Szombathely, Hungary

Nowinszky L (2004) Nocturnal illumination and night flying insects. Appl Ecol Environ Res 2:17–52

Nowinszky L (2008) Moonlight and lunar phases. In: Nowinszky L (ed) Light trapping and the Moon, 1st ed. Savaria University Press, Szombathely, pp 47–104

Nowinszky L, Puskás J (2010) Possible reasons for reduced light-trap caches at a full moon: shorter collecting distance or reduced flight activity. Adv Biores 1:205–220

Nowinszky L, Puskás J (2011) Light trapping of *Helicoverpa armigera* in India and Hungary in relation with moon phases. Ind J Agric Sci 81:152–155

Nowinszky L, Puskás J (2012) Light-trap catch of the harmful moths depending on moonlight in North Carolina and Nebraska States of USA. Int Sch Res Net ISRN-Zool 238591. https://doi.org/10.5408/2012/238591

Nowinszky L, Puskás J (2013) Light-trap catch of harmful Microlepidoptera species in connection with polarized moonlight and collecting distance. J Adv Lab Res Biol 4:108–117

Nowinszky L, Puskás J (2014) Light-trap catch of *Lygus* sp. (Heteroptera: Miridae) in connection with the polarized moonlight, the collecting distance and the staying of the moon above horizon. J Adv lab res. Biol 5:102–107

Nowinszky L, Tóth G (1987) Influence of cosmic factors on the light-trap catches of harmful insects Dissertation, PAS University, Keszthely. (in Hungarian)

Nowinszky L, Szabó S, Tóth G, Ekk I, Kiss M (1979) The effect of the moon phases and of the intensity of polarized moonlight on the light-trap catches. J Appl Entomol 88:337–355. https://doi.org/10.1111/j.1439-0418.1979.tb02512.x

Nowinszky L, Barczikay G, Puskás J (2010) The relationship between lunar phases and the number of pest Microlepidoptera specimens caught by pheromone traps. Asian J Exp Biol Sci 1:14–19

Nowinszky L, Hirka A, Gy C, Petrányi G, Puskás J (2012a) The influence of polarized moonlight and collecting distance on the catches of winter moth *Operophthera brumata* L. (Lepidoptera: Geometridae) by light-traps. Eur J Entomol 109:29–34. https://doi.org/10.14411/eje.2012.005

Nowinszky L, Kiss O, Szentkirályi F, Puskás J, Ladányi M (2012b) Influence of illumination and polarized moonlight on light-trap catch of caddisflies (Trichoptera). Res J Biol 2:79–90

Nowinszky L, Puskás J, Barczikay G (2015) The relationship between polarized moonlight and the number of pest microlepidoptera specimens caught in pheromone traps. Pol J Entomol 84:163–176. https://doi.org/10.1515/pjen-2015-0014

Pristavko VP, Karasov VS (1981) The role of variation of geomagnetic field associated with other abiotic factors influencing the fly activity of insects. Minsk 2:90–193

Romeis J, Shanower TG (1996) Arthropod natural enemies of *Helicoverpa armigera* (Hbn.) in India. Biocontrol Sci Techn 6:481–508. https://doi.org/10.1080/09583159631136

Samia MM, Saleh Layla AH, Al-Shareef R, Al-Zahrany AA (2010) Effect of geomagnetic field on whitefly *Bemisia tabaci* (Gennadius) flight to the cardinal and halfway directions and their attraction to different colours in Jeddah of Saudi Arabia. Agric Biol J North Am 1:1349–1356. https://doi.org/10.5251/abjna.2010.1.6.1349.1356

Scott KD, Lawrence N, Lange CL, Scott LJ, Wilkinson KS, Merritt MA, Miles M, Murray D, Graham GC (2005) Assessing moth migration and population structuring in *Helicoverpa armigera* (Lep.: Noctuidae) at the regional scale: example from the Darling Downs, Australia. J Econ Entomol 98:2210–2219. https://doi.org/10.1093/jee/98.6.2210

Shimoda M, Honda K (2013) Insect reactions to light and its applications to pest management. Appl Entomol Zool 48:413–421. https://doi.org/10.1007/s13355-013-0219-x

Srygley RB, Oliveira EG (2001) Sun compass and wind drift compensation in migrating butterflies. J Navigation 54:405–417. https://doi.org/10.1017/S0373463301001448

Tshernyshev WB (1972) The catches of insects by light trap and solar activity. Zool Anz 88:452–459

Tshernyshev WB, Danthanarayana W (1998) Laboratory study of flight in some noctuids (Lepidoptera: Noctuidae: Heliothinae). 2. Activity from day to day. Russ Entomol J 7:96–100

Völgyesi L (2002) Geophysics, 1st edn. Budapest University of Technology and Economics Press, Budapest

Wehner R (1984) Astronavigation in insects. Ann Rev Entomol 29:277–298. https://doi.org/10.1146/annurev.en.29.010184.001425

Wehner R (1992) Hunt for the magnetoreceptor. Nature 359:105–106. https://doi.org/10.1038/359105a0