

Balls of Light: The Questionable Science of Crop Circles

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Abstract—Three papers published by W. C. Levensgood (1994), W. C. Levensgood and N. P. Talbott (1999) and by E. H. Haselhoff (2001) suggested the involvement of some kind of electromagnetic radiation during the creation of crop circles. Here we discuss the methods and conclusions of the three articles, pointing out the misrepresentation of the experimental protocols, the misleading application of statistical procedures, the arbitrary discarding of unwanted results and the weakness of the proposed physical model to the suggested hypothesis. In particular, we show that Haselhoff's conclusions are unsubstantiated and do not prove the involvement of an electromagnetic radiation source in the creation event.

Keywords: crop circles—balls of light—electromagnetic radiation—
statistical models—stem node elongation

The official history of mysterious circular patterns appearing in crop fields began in 1980 when Dr. Terence Meaden's attention was drawn to a formation in a field of oats near Bratton (England) beneath the steep grassy slopes upon which the famous White Horse of Westbury is cut into the underlying chalk (Meaden, 1991).

These "first" circles were called "mystery circles" or simply "rings", but since circa 1988 they became identified all over the world as "crop circles". Crop circles consist of geometrical crop regions, in which the plants (primarily cereals crops) are flattened in a horizontal position.

Over the years, crop circles rapidly gained media attention, evolved from simple circular shapes to more and more complex patterns, and their number increased from dozens at the beginning of their documented appearance to hundreds only some years later. During the 1980s and 1990s, for example, the

number of circles appearing in Britain grew rapidly from only a handful per year in the early 1980s to dozens by the end of the decade and to several hundred in the U.K. alone in 1991.

Many people during the years admitted they had made the circles themselves, but in spite of these confessions, the "believers" continued to deny claims of human involvement as the only origin of the whole phenomenon. Many alternative theories proliferated attempting to explain the possible non-human mechanisms for the circles' creation. Most of the claims about circles were nothing but mere hypotheses that never gained sufficient reliability to hold up upon examination by a peer-reviewed scientific journal. Only three studies were published in a scientific journal: the first one was authored by W. C. Levensgood (1994), the second one by W. C. Levensgood and N. P. Talbott (1999), and the last one by E. H. Haselhoff (2001). All three papers suggested the involvement of some kind of electromagnetic radiation during the circles' formation. However, in those three papers a list of sufficient conditions (or at least necessary conditions) was not provided in order to establish without any doubt if a geometric formation has or has not been made by man.

Levensgood (1994) asserted he had found anatomical alterations (the so-called anomalies) in crop formations which could not be accounted for by assuming a man-made origin of the circles. Among other anomalies that we are not discussing here, he observed an allegedly "anomalous" expansion of the stem nodes of the plants lying inside the crop circles when compared to those outside them (this was the so-called alpha-test, i.e. the ratio of the stem length to iude length).

Levensgood concluded that these alterations were probably caused by a thermo-mechanical effect due to a thermal expansion of the cell walls directly related to an absorption of electromagnetic energy. During an experiment carried out in Maryland in 1997, Levensgood and Talbott (1999) made, by themselves, a crop circle, claiming that the gravitropic response of the flattened plants was no more than about 10% in the three days since the circle creation, too little to explain the elongations observed in the alleged "genuine" formations. We will discuss this assumption later in this paper.

In 1999 Levensgood and Talbott (1999) published the results of the monitoring carried out on three simple circular formations at Devizes (England, 1993), Chehalis (Washington, USA, 1994) and Sussex (England, 1994). A fourth case is reported, analysing a more complex spiral formation which appeared in a barley field in Beckhampton (England) in 1995.

It is very important to highlight that two of the three crop circles appeared in areas where numerous known circle-makers live and have been creating crop circles for over a decade. The Devizes formation appeared in an area near Beckhampton, Wiltshire, close to where the first major crop circle hoax occurred at Bratton in July 1990 ("Operation Blackbird"), where an earlier hoax sponsored by national newspapers took place in 1983, where a major group of circle-makers called the "United Bureau of Investigation" lived and made circles

TABLE 1
 Experimental Data Measured at Devizes, Chehalis and Sussex Formations. Distance (d) From the Circle Centre and Average Node Length (N_L) Are Reported. The Apex ^c Indicates Data Measured at Standing Central Tufts; Data Indicated With the Apex ^e Are Exterior to the Circle Diameter

Devizes		Chehalis		Sussex	
d (m)	N_L (mm)	d (m)	N_L (mm)	d (m)	N_L (mm)
0.303	6.0	1.110	4.1 ^c	0.315	4.6 ^e
1.510	4.4	1.825	3.7	1.558	3.5
1.529	5.5	4.543	3.5	4.476	3.3
2.812	4.4	9.109	3.3	4.830	3.4
2.897	4.3			12.224	2.8 ^e
3.300	3.3 ^e			19.775	2.4 ^e
control	3.2	control	2.9	control	2.4

from 1990 to 1991, and where the Wessex Skeptics made formations to test crop circle researchers in the early 1990s. The Sussex formation appeared in an area where the evidence for crop circle hoaxing was less overwhelming than at Beckhampton but where a number of possible circlemakers live. Samples were taken from an area where even the most paranormally inclined crop circle researchers have subsequently admitted that crop circle hoaxing is rife. These samples are also close to the two areas where Doug Bower and Dave Chorley allegedly began making crop circles in the 1980s (South Wiltshire, Alfriston, East Sussex). Both areas appear to have attracted considerable copy-cat hoaxing of the original Doug and Dave circles.

Levengood and Talbott collected groups of 10–15 plants at each sampling location, defined by the distance from the centre of the circle, and averaged their stem node lengths. By plotting the distance from the centre of the circle against the logarithm of the group averages of the stem node lengths they found a linear relationship between the two variables. Thus, the node lengths seemed to decrease from the centre to the edges of the flattened areas following a negative exponential trend (Table 1). The authors suggested that this behaviour agreed with an electromagnetic energy absorption caused by plane wave fronts propagating in the air, according to the Beer-Lambert law, and striking the plants. They described the relationship between the node lengths and the radiation intensity as:

$$N_L = b(I/I_0) = b(e^{-acd})$$

where N_L is the node length, b a proportionality constant, a the absorption coefficient of the air, c the concentration of absorbing molecules, I_0 the radiation source intensity and I the radiation intensity at distance d from the source.

Two years later, Haselhoff (Haselhoff, 2001) criticised this paper, pointing at two major flaws: the normal node length was assumed to be zero and energy spreading with distance was not taken into account. He then suggested correcting

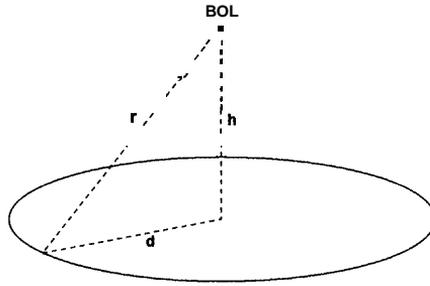


Fig. 1. Geometric representation of the BOL coordinates.

the first error by subtracting a term N_0 , representing the average node length of undisturbed (control) plants outside the formations. He implicitly accepted both the questionable sampling strategy of the Levensgood and Talbot experiments and the thermo-mechanical hypothesis explaining the node elongation.

Haselhoff's focus was on a new model for the electromagnetic radiation allegedly involved in the circles' creation. Analysing the data of the first three above-mentioned formations, Haselhoff identified a reciprocal quadratic trend for the stems' elongation with radial distance. Therefore, he proposed an electromagnetic point source model, assuming it as a "Ball Of Light" (BOL) irradiating the underlying crop field. In order to support his hypothesis he reported, as a counter-proof, the results of a study carried out on a surely man-made formation in Nieuwerkerk in 1997, in which the same reciprocal quadratic trend seemed not to be evident.

The BOL hypothesis consisted of a model describing the decrease with distance of the intensity of a spherical electromagnetic wave front centred at a point source located at a finite height, h , above the field (Figure 1). Though not reported in the article, the model equation can be obtained by simple physical considerations, assuming a $1/r^2$ decrease of the field intensity multiplied by a proportionality constant:

$$N_L - N_0 = b/r^2$$

where b is the proportionality constant and $r^2 = d^2 + h^2$, where d is the distance on the ground from the centre of the circle and h the height of the hypothetical source from the centre of the circle. For each formation the parameter h was optimised to best fit the data to a $1/r^2$ decrease. Scaling the x axis as $1/r^2$ and putting $N_L - N_0$ as the ordinates, if the BOL hypothesis is correct, a high coefficient of multiple determination (R^2) is expected.

Discussion

Because of the sensational scientific contents of this finding and the great impact exerted on world-wide public opinion, a more exhaustive inspection of

the data handling and the statistical analyses seems to be mandatory according to the accepted rule that extraordinary claims require extraordinary proofs.

Before starting the discussion, we believe it important to highlight that the three articles above mentioned are actually considered by the crop circle community to be the "scientific reference point" on the subject. *Physiologia Plantarum Journal* played a crucial role in publishing all three articles and giving these authors scientific support and credibility. Furthermore, our article was first submitted to *Physiologia Plantarum Journal* and its editorial board agreed with our comments about the pseudoscientific contents of the three articles (*Physiologia Plantarum Journal*, communication to the authors, 2004), but it refused to publish our article with the surprising motivation that "there is not a scientific discussion going on the crop circle subject".

Our first remarks to Haselhoff's paper concern the sampling strategy and the statistical approach. Both the number of circles taken into account and the number of samples collected inside and outside each formation are inadequate to carry out a reliable statistical analysis.

It is noticeable that in his 2001 article in *Physiologia Plantarum Journal* the number of samples taken at each site is not listed. This is a surprising omission, as most scientific papers list sample sizes to help demonstrate that the statistical patterns they discuss are not limited to just a few data points. This is an important consideration, as Haselhoff's 2001 *Physiologia Plantarum Journal* paper clearly implies that the effect they claim to have discovered applies to many crop circles, not just a few.

In the case of the Chehalis set, for example, data were collected from only three sampling points, so it is not surprising that a two-parameter model can fit three points rather well, though this carries no indication for a cause-effect relationship.

Moreover, the BOL model is characterised by two parameters: the height, h , of the BOL from the ground, and the proportionality constant b . The parameter b is not so meaningless as to be superficially neglected in Haselhoff's paper, but it should play a crucial role in the undergoing process. As a matter of fact, the parameter b contains all the non-geometrical information. In reality, it represents a set of multiple variables rather than a constant. It describes all the physical properties of the phenomenon, such as, for example, the radiation duration, the spectral range of the emitted light, the source intensity, the air absorption, the moisture content in the plants and the surrounding soil, the absorbing and reflecting properties of the plants and the ground, and so on.

In the cases of the formations at Devizes and Chehalis, both inside a wheat field, we found, respectively, $b = 10.3$ and $b = 68.9$; these are very different values. Not only did Haselhoff omit an explanation of the meaning of the parameters and their actual differences but he also omitted an indication of their values. In particular, only the height, h , is listed in table 1 of Haselhoff's paper. As a consequence, the BOL model may seem to possess only one parameter, the height h , and an apparently high performance for a model with just one parameter.

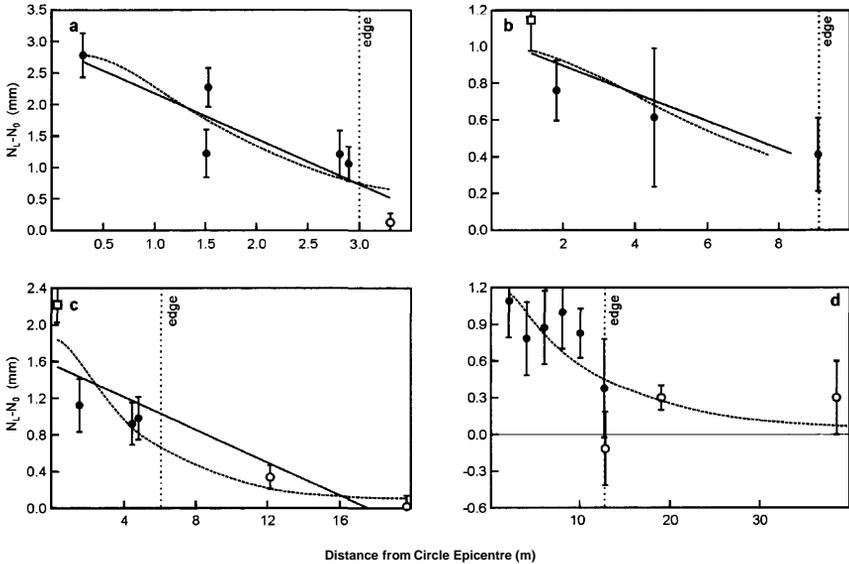


Fig. 2. BOL (dashed line) and simple linear regression analysis comparison for (a) Devizes, (b) Chehalis, (c) Sussex and (d) Nieuwerkerk formations. The central tufts data are included in the analysis. Empty square symbols indicate standing central tufts data; empty circles indicate samples collected outside the crop circle diameter.

Another remarkable point concerns the lack of a standardized criterion for the inclusion of data sets in the control group. Some plants taken very far from the formations were defined as "control" and considered as undisturbed samples; their average values and standard deviations were calculated in order to allow a comparison between affected and unaffected plants. Bent plants inside the formations were considered "affected" (i.e. non-control). As a matter of fact, even some upright plants, taken outside the formations, were considered affected and not control: two samples at the Sussex formation were collected about 6 and 14 m away from the circle limit, and one sample at Devizes was collected 30 m outside the formation (Figure 2a and c). No justification for this decision is provided in the paper. No distance threshold for inclusion in the control group is mentioned. We have to suppose that the authors decided to assign these plants to the "affected" group rather than to the control group after seeing that their nodes were longer than those of other control plants. This procedure is bound to produce biases.

There may be some reason to include a few external upright plants in the "affected" group, since the authors seem to be looking for effects that might not necessarily be restricted to the flattened area. However, if an objective criterion is not clearly stated up front, any subsequent analysis becomes questionable, because the standard deviation of the control level may be underestimated, allowing affected values to look more anomalous than they are.

Moreover, if the circle border is not used as a criterion, it becomes more difficult to ensure that the effect being analysed is actually caused by the creation of the circle and not by other concurring reasons. This is particularly relevant considering that the analysis lacks spatial resolution because of the small number of samples included and considering that control plants are taken only very far from the circle, where environmental conditions might have been slightly different. No statistical tests have been applied to compare means and variances of samples taken inside and outside the formations. Any conclusion concerning the comparison of samples coming from the formations and those from the whole crop field are therefore not supported by a robust statistical analysis.

Figure 2a through c shows the data from the Devizes, Chehalis and Sussex formations. The radii of the three circles were, respectively, 3, 9 and 6 m, and all the outside standing plants should be considered as control samples, unless a different criterion is defined.

Nevertheless, the first right point in the Devizes graph and the first two in the Sussex one were reported and fitted in the regression models by both Levengood & Talbott and Haselhoff, in spite of their true nature as controls. Especially surprising is the Sussex case, in which the control level confidence interval is very small, while one of the samples (control) is very far from it. Clearly, this point was excluded from the calculation of the standard deviations of the control levels, giving rise to lower than actual values and thus avoiding a reliable comparison between the inside-circles node length variability and that of the whole crop field.

At the Sussex and Chehalis formations, circular shaped epicentre tufts of standing plants occurred, but these data were discarded from the regression analyses, in spite of the fact that those plants belonged to the core of the circle and despite the importance of those samples as a result of their proximity to the alleged radiating source. Levengood and Talbott excluded the central point, although, thanks to the omission of the energy spreading factor, it was not a singularity in their exponential model. Although Haselhoff might have left out the central tufts in order to compare his results with those of Levengood and Talbott, he should have included them in order to correctly evaluate the performance of the model.

Moreover, we question the lack of information about the statistical significance of the BOL model parameters. This is a crucial task, because it invalidates the reliability of the linear regressions based on the h -optimised transformation of the x axis. Repeating Haselhoff's regression analyses with the original data, we found that the parameter h was not statistically significant at a $\alpha = 0.05$ level (Table 2a); that is indeed a generous limit for an unusual claim. Including the central tufts into the data sets, both the coefficients of multiple determination (R^2) and the statistical significance of the parameter h decrease (Table 2a); thus, the BOL model appears statistically meaningless, or, at least, it is not significant enough to be sufficiently confident in the existence of an electromagnetic point source radiating the crop circle.

TABLE 2a

Parameters of the BOL Model Applied to the Chehalis, Sussex and Devizes Data. R^2 is the Coefficient of Multiple Determination, the Parameter h is the Height Above Ground for the Radiating Point Source, p -Value of h is the Probability (Ranging from 0 to 1) That the Actual Parameter is Zero. Haselhoff Results Were Obtained Excluding the Standing Plants at Central Tufts. Both Excluding and Including the Central Tufts, the BOL Model Parameters Are Not Statistically Significant at the 95% Confidence Interval (Because the p -Value of h is Greater Than 0.05). The Inclusion of Standing Plants in the Central Tuft is Not Applicable for the Devizes Formation

	Excluding standing plants of central tuft			Including standing plants of central tuft		
	Chehalis	Sussex	Devizes	Chehalis	Sussex	Devizes
R^2	0.99	0.97	0.78	0.78	0.84	—
h	9.5	7.8	1.9	6.3	4.4	—
p -value of h	0.09	0.07	0.13	0.30	0.17	—

We point out also that a simple linear regression, with the same number of parameters, fits the data sets better than the BOL model (Table 2b). Of course, we are not suggesting the existence of a specific underlying linear phenomenon, we are only pointing out a basic concept: correlation is not proof of causation. Furthermore, it is very important to remark that performing statistical tests with so little data is likely to result in "freak" results which are unlikely to be statistically significant.

From a physical point of view it should be pointed out that the BOL model is not realistic. A hypothetical BOL model should be much more complex, because the striking energy will depend on the incidence angle of the radiation on the stem nodes and the energy absorption will depend on the path length of the radiation inside the plants and therefore on their actual transparency. A non-transparent stem partially shields the node, so Haselhoff's model is only valid if we assume that the plants are completely transparent to the striking radiation and so could not absorb energy at all. Therefore, if a light point source really radiates an underlying crop field, its imprint should not show, anyway, a $1/r^2$ decrease

TABLE 2b

Parameters of a Linear Regression Model Applied to the Chehalis, Sussex and Devizes Data. R^2 Is the Coefficient of Multiple Determination and a is the Slope Parameter. A Simple Linear Regression Fits All the Data Sets With a Higher Statistical Significance; in the No-Tuft Case Considered by Haselhoff, It Fits Even Better

	Excluding standing plants of central tuft			Including standing plants of central tuft		
	Chehalis	Sussex	Devizes	Chehalis	Sussex	Devizes
R^2	1.00	0.98	0.80	0.77	0.75	—
a	-0.048	-0.063	-0.74	-0.075	-0.089	—
p -value of a	0.03	0.001	0.02	0.12	0.02	—

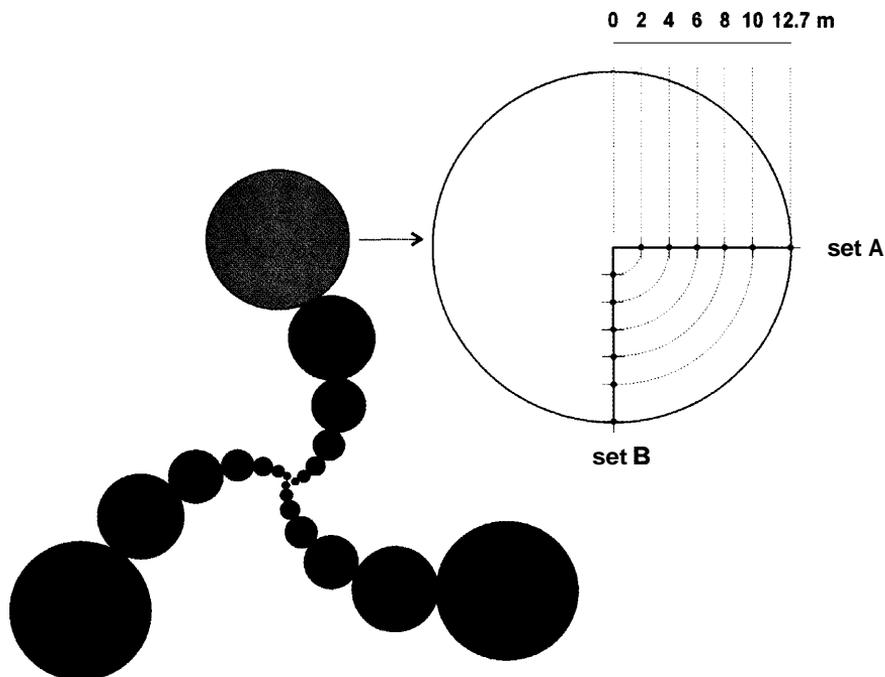


Fig. 3. Schematic representation of the Nieuwerkerk man-made formation. The light grey circle in the formation is the sampled one. On the upright, a zoom of the sampled circle with the indication of the sampling points. Both sets A and B were gathered by Haselhoff, but only set A was published. Set B never appeared in Haselhoff's paper.

trend. We obtained from Haselhoff (Haselhoff, communication to the authors, 2003) the original measurements taken at the Nieuwerkerk man-made formation (Figure 3), and we compared them with those reported in Haselhoff's paper. First, it should be noted that the node lengths increase up to 30%, proving wrong the conclusions of the Levensgood and Talbott experiment at Maryland (1997), in which plant gravitropism was estimated to be no more than about 10%, meanwhile demonstrating that man-made circles can have node elongation as large as those found in the reputedly non-anthropogenic ("genuine") formations.

Furthermore, examining the Nieuwerkerk case, we noticed that this time, the first external sample point was excluded by the analysis, though it was located only 10 cm beyond the circle edge (i.e. 12.8 m from the circle centre). Including this sample into the regression analysis, as needed to make a coherent comparison with the analyses carried out on the other "genuine" formations, the correlation coefficient for the BOL model changes from $R = 0.54$ to $R = 0.63$.

What was most surprising, however, was the discovery that only a part of the experimental data was published in the article. During the experiment, Haselhoff gathered two sample sets, indicated as A and B, following two orthogonal directions on the same circular imprint, but only set A was published. The

correlation coefficient for the BOL model applied to set B is $R = 0.71$, significantly higher than that of set A.

By using both data sets and averaging the values of the points located inside the circle at the same distance from the centre (Figure 2d), we found that the correlation coefficient for the BOL model increases to $R = 0.73$. Moreover, including also all the available data belonging to the outer part of the circles and using as control value the average of all the outside samples, the correlation coefficient increases to $R = 0.83$. We conclude that plants collected at man-made formations can reveal statistical features similar to those of the "genuine" crop circles.

Another point worth noticing is the lack of the analysis of the Beckhampton spiral formation, though this experiment is fully described in Levensgood and Talbott's article, as commented on by Haselhoff. As a matter of fact, the Beckhampton formation does not show a $1/r^2$ trend; its node lengthening does not even seem correlated with distance. We point out that all experiments have to be taken into account and that a theory is reliable only when it explains all cases and not only those that agree with it.

It might be argued that, in order to draw a spiral on the ground, a BOL might have to move in a complex way, instead of just staying still over the centre; this movement would prevent the $1/r^2$ trend from appearing in the data, thus justifying the exclusion from the analysis.

However, this rationale would lead to questioning beyond the scope of the three articles. It is normally accepted by "believers" that crop circles are made by intelligent beings, because (allegedly) natural phenomena could not draw such a wide variety of complex geometrical symbolic patterns. However, this compelling evidence is not present in simple round or irregular (non-geometrical) shapes. If an article focuses only on simple circles, its conclusions cannot be extended to complex circles without relying on the implicit, questionable assumption that only one cause of stem bending can ever exist. If an article does not address complex shapes, then its relevance for what people call "crop circles" has yet to be demonstrated.

Another crucial criticism concerns the inconsistency of the assumptions. In Levensgood and Talbott's article, an intense and rapid heating of the plant tissues is suggested as a consequence of the radiation absorption. The pressure rise, caused by the water heating, should stretch the viscoelastic node tissues, elongating them. In his article, published in 1994, Levensgood stated that "if microwave energy is involved in crop formations, the amount of heating would depend on plant water content". However, the thermal expansion of liquid water from 15°C to 90°C is no more than 3.5% and can not account for node expansions in the range of 30% to 200%, like those measured in the formations (Levensgood & Talbott, 1999).

Furthermore, both Levensgood and Talbott (1999) and J. A. Burke (1998), a member of the same research team (BLT), asserted that plant damages (node elongations) of greater magnitude occur within the irregularly outlined crop formations attributed to the wind and/or to severe weather conditions.

All the hypotheses formulated about the circles' creation were based on a thermo-mechanical effect, but the authors never demonstrated the possibility for the stem nodes to lengthen up to 200% or even to 100%, as observed in the "genuine" formations, under heating. It should not be a difficult task to verify whether crop stems indeed elongate under the action of radiant heat (without burning or killing the plants); but as long as this kind of laboratory evidence for the thermo-mechanical effect is not provided, node elongation as great as those allegedly observed for crop formations cannot be related to an electromagnetic radiation absorption.

A further criticism concerns the lack of detailed information in every topic treated in the papers: no photograph is shown of the three "genuine" circles and the Nieuwerkerk "hoax"; no table is reported with the original data; no description is provided for the flattening geometry (i.e. nothing is said about the positions of the bent plants); nothing is said about where the samples were collected inside the circles, except for their distances from the centre. Thus, the study does not allow a two-dimensional analysis; no uncertainty is supplied about the abscissa, whereas each point represented the average of the stem length of 10–15 plants and small differences in the distance from the centre produce enormous variations in the stem elongation, as in the case of the Devizes formation, where the second and third points are only 1.9 cm apart, while their elongation differs by 86%. No hypothesis is put forward about the duration, intensity and frequency of the alleged radiation. Finally, the opacity of the plants, involving the incidence angle of the radiation on the stems, can dramatically change the symmetry of the energy absorption mechanism and so too, the model equation; this factor is totally ignored.

Conclusions

We conclude that the claims about the involvement of some kind of electromagnetic radiation in the creation of crop circles are not supported by the available evidence. In particular, the $1/r^2$ symmetry exists only as a consequence of the unjustified exclusion of unwanted data; even in this favourable condition, the suggested model does not fit the data as well as a simple "best fit" straight line. Even if a $1/r^2$ trend were found, it should not, anyway, be related to a point source radiating the exposed crop field, because this implies a complete transparency of the plants to the striking radiation, so avoiding the absorption of energy. Moreover, the BOL model was selectively applied only to circular imprints, while all other geometric crop formations with rectangular or more complex patterns were deliberately ignored because they cannot fit the BOL hypothesis. The total evidence discussed in this critical review demonstrates nothing but a mere difference in the stem elongation between the flattened plants lying inside the circles and those standing outside it, as we should expect when whatever kind of mechanical force flattens the plants, rope and wood plank included.

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