Article

Methods Of Forecasting The Activity Of Pests In Orchards With Use Of Sensor Measurements

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Abstract: A very well–established position in horticultural crops in Poland is occupied by fruit orchards and, to a large extent, apples. Every human activity with nature is subject to the threat of parasites using fruit harvest as a chance for further survival and development. One of the most dangerous is the *codling moth* pest, which can cause desolation in an orchard. The most effective solution to eliminate the pest is spraying, but they require an active contact with it and the exact period of its activity. Currently used methods, based on pheromone traps, are long and manual processes. The research discussed in the article aims to introduce the automation of this process based on the concept of a temperature curve using electronic sensors (iButton) collecting data. The data acquired over time made it possible to prepare the sensory values of the data dependent on the effectiveness of traditional counting methods. An effectively designed IoT system and knowledge of the problem can improve fruit growers' work while minimizing damage.

Keywords: orchards monitoring; pests activity; rainfall monitoring; temperature measurements; soil moisture; prediction model; evapotranspiration;

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1. Introduction

According to the report of the Association of Polish Fruit and Vegetable Distributors "Fruit Union", Poland in the fruit–growing sector in Europe, together with Spain and Italy, belongs to three countries where 2/3 of the total area of fruit plantations in the EU is concentrated. Poland has an 11% share in the entire fruit production market and a 26% share in the production of the apples mentioned in this article. Compared to 2012, the area of fruit plantations in the European Union increased only slightly by 0.4%, while in Poland alone, it increased by 11%. Thus, the key importance of protecting orchards (especially apples) is an important turning point for us in developing and promoting the country.

Codling moth (*Cydia Pomonella*) is one of the most dangerous pests of apple trees, well known for over 50 years [1,2]. The caterpillars of the pest grow up to 20 mm and are cream, then pink with a brown head. This apple pest develops two generations during the growing season. Caterpillars of the second generation often nibble 2 or 3 adjacent apples before biting into the right fruit, which increases losses. The harmfulness of the apple fruit moth's caterpillars consists of biting into the flesh and digging channels up to the seed chamber, leaving faeces in them. The flight of butterflies lasts from May to August, and from June until harvest, you can find caterpillars that feed on the fruit, causing them to become verminous.

The fruit damaged in this way loses its commercial value on the dessert fruit market and is mainly intended for processing. According to the Department of Agrophage Forecasting Methods and Plant Protection Economics of the Institute of Plant Protection in Poznań, the share of damaged apples in 2003 in Poland was 6%. In the following years [3] this value did not change and remained at even over a dozen per cent. At the same time, it should be noted that the number of codling moths in orchards is constantly increasing. Its uncontrolled population can lose up to 80–90% of the apples in the orchard. Therefore, fighting this pest becomes necessary from an economic point of view, which Płuciennik pointed out [4,5] in her research.

The most popular method of controlling this pest is chemical treatments performed following the deadlines recommended by the State Plant Health and Seed Inspection Service (PIORIN), which monitors the presence of the pest in Poland. However, it often turns out that the dates set by PIORIN are only optimal for some apple orchards located in a given district, which means that the protective measures performed are ineffective. This problem occurs mainly when the protected orchard is located in a different area than the orchards where observations for signaling are carried out. Figure 1 shows the division of Poland into main voivodeship stations and district stations for the Mazowieckie voivodship. The average district in Poland is 994 km^2. Table 1 lists the dates of the appearance of the codling moths in Poland in the years 2002–2005. These years begin a research cycle, the effect of which is the content presented in this article. The results, repeated regularly every year, are similar to the first ones obtained. Hence the references in the article will be based on the first four research years of the project. Despite the passage of time and climate warming, the pest's life cycle has been preserved to this day. Also the passage of years PIORIN notifications ("alerts") are too generic with no specific dates and, very often almost a day or two before the actual date of the suggested action. There were also years when the message was made after the pest had started flying. As shown by these data, the time spread of this pest's activity is wide – in some years, it was over 50 days, depending on the location of the field observation point. For example, in 2003, in the Sandomierz district, the first specimens appeared on May 26, while in Ostrowiec Świętokrzyski (44 km far from the first location), on May 23, the codling moths were already in the "black head" stage.

(a) Division into voivodeship PIORIN stations.

(b) Division into district PIORIN stations.

Figure 1. Signaling areas for PIORIN

From 1 January 2014, every professional fruit grower is obliged to apply the principles of integrated pest management following the provisions of Art. 14 of Directive 2009/128/EC and Regulation No. 1107/2009. The basis of this document is to maximize the use of non–chemical plant and fruit tree protection methods, supplementing them with pesticides only in exceptional cases. From an economic point of view, the losses caused by pests are higher than the cost of regular treatment, including the cost of the "permitted" protection measures compliant with the requirements of the European Union. Under the general principles of integrated pest management in Annex III to Directive 2009/128/EC,

Table 1. The date ranges for the appearance of the codling moth in Poland

Param	First species flight				"Black head"			
	2002	2003	2004	2005	2002	2003	2004	2005
First day	May 4	May 8	Apr 24	May 2	May 2	May 23	May 17	May 26
End day	May 22	May 26	Jun 14	Jun 15	Jun 26	Jun 12	Jun 24	Jun 20
Tot. d-s	18	18	51	44	55	20	38	25
Stations	13	14	22	24	12	13	21	23

non–chemical methods (biological, physical, breeding) should be preferred over chemical methods. However, using a limited resource of solutions is not very effective, safe and cost–effective in reducing the population of pests to a level at which they no longer cause economic damage.

To achieve this result, research is being carried out to understand pests' biology, spread and harmfulness, including forecasting their activity in conjunction with risk assessment [6]. The results of these studies also consider the conditions related to the relationship between a given pest organism, the plant itself (in this case, the fruit of an apple tree) and the environment (here, the consumer should also be understood as a human being). It is also related to the concept of evapotranspiration and the circulation cycle of water and components dissolved in it to and from the atmosphere [7–9]. The interaction of these elements and the conditions present in a particular orchard determines the activity of the pest and its actions.

About 20 years ago, biological scientists conducted intensive research on a virus affecting the development of the butterfly [10,11] – *Cydia pomonella granulovirus*. Based on its functioning, many analyzes were also made (including [12]) on the use of virus fragments to reduce the pest population without increasing the risk of the harmful effects of spraying on humans and other insects pollinating the inflorescence, such as bees or pollen butterflies [13–15]. The dates of the pest's activity presented in the table apply to the entire country. The activity of codling moths, however, may be different even in a small area, such as one town or even a single orchard. In the years 2002–2003, in production orchards near Łosice, field research [16] was carried out, which shows that the activity of moths can be variable even in the area of one plot with different topography. Therefore, in order to determine the optimal date of treatment with chemical plant protection products, it is necessary to forecast the occurrence of codling moths in a given orchard or even a specific plot.

One of the ways of signaling the appearance of codling moths is the use of pheromone traps. They should be planted in the orchard in the third decade of April or early May and the number of caught butterflies should be constantly monitored. In Poland, the threshold of economic threat is considered to be 7 males per week per trap (in later years, due to increasing losses in orchards, this number has changed in range between 4 and 9 per week per trap). In other countries, the threshold is 2–10 moths per trap per week [17]. Such a pest signaling mechanism is almost reliable and easy to use. However, a big disadvantage of this solution is the necessity to check the traps regularly and to calculate the threshold on a regular basis. If the orchard uses several traps, this solution becomes very problematic. Another disadvantage of this solution is the inability to predict the number of pests in the near future. On the other hand, in the Castro [18] study, the day and night mode was strongly linked to the effectiveness of pheromones and volatile substances sprayed in the orchard. The optimal action is the fact that not only is less substance sprayed, but also more physical contact is preserved with the moth, reducing the probability of egg laying.

The codling moths, like any insect, is a cold–blooded organism [19]. Therefore, to determine the date of the appearance of this pest, we can use meteorological data. The most widespread are models based on the sum of the effective temperatures [20]. Similar research in this area was also conducted in the works of Kozłowski [21] and Juszczak [22]. The use of this type of model in conjunction with a modern system of measurement sensors allows for the automation of the process of predicting the occurrence of hazards from codling moths. Moreover, for weather data it is possible to predict missing data on the basis of collected measurement data, which was presented by Kocian [23]. In this way, even in the absence of several measurement data, it is possible to correctly forecast the missing data. By using the possibility of forecasting the temperature that can be expected in the coming days [24], it is possible to forecast the appearance of a pest, and thus it is possible to apply protective measures in the optimal time.

2. Materials and Methods

The traditional forecasting method uses published by a country–specific unit dealing with the collection of weather data and indications in the scope of taken protective measures or a consulting company in the field of plant protection. In Poland, such a center is PIORIN (State Plant Health and Seed Inspection Service). These data, however, are based on precise measurements, but due to the low coverage in the local area, they constitute serious deviations from the actual state of affairs. This is important because the presence of codling moths is strongly related to local conditions. A delay in the grower's response to conditions conducive to the initiation of moth flight may cause irreparable losses to the harvest.

In order to verify the above theories and to prepare appropriate automatic methods, a measurement project was prepared, which in combination with pheromone traps set up in the orchard [Figure 2, 3] was to confirm the effectiveness of local measurement methods in fighting the pest .

Figure 2. General view of pheromone trap on apple tree

The diagram [Figure 4] shows the physical layout of the sensors in the local orchard. There are many orchards in the area of one district. Each such orchard covers an area of several dozen hectares. The research orchard mentioned in the article covers an area of 30.000 square meters (3 ha) and consists of three plots with dimensions of 50 [m] × 600 [m]. The quarters where the research was carried out were uniformly planted with six–year–old apple trees of the Jonagold variety.

As part of the research, it was decided to place three sensors (S1, S2, S3) in one quarter (Quarter 2), placed in the treetops near pheromone traps. The sensors are placed in the central axis of the quarters along the entire length at equal intervals of 150 [m]. The use of this type of devices is carried out in tests where it is required to read and record the local

Figure 3. Side view of the pheromone trap

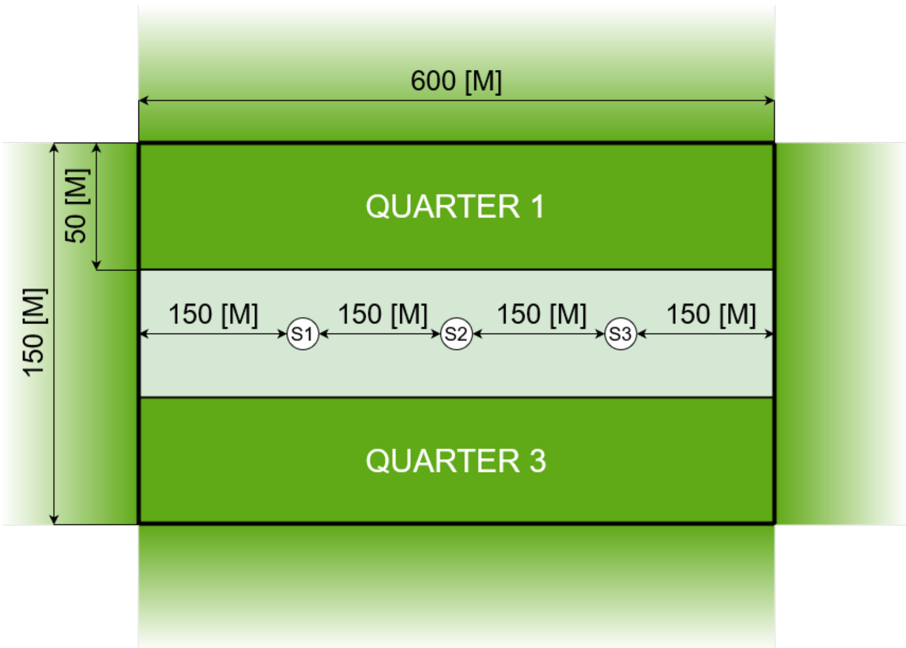

Figure 4. Top orchard schematic view with dimensions and sensors location

temperature directly at the measuring site [25,26]. The advantage of such a solution is high efficiency, a large range of resistance to unfavorable weather conditions, as well as a low price of the solution.

Thermochron ® and iButton ® DS1921G devices by Maxim Integrated company were used to measure the external temperature. Those devices are integrated, self–sufficient system that measures temperature and store the obtained results in the protected memory section [Figure 5].

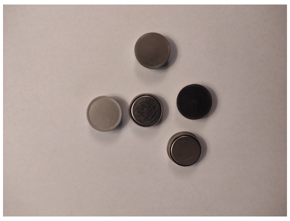

Figure 5. iButton system used in project

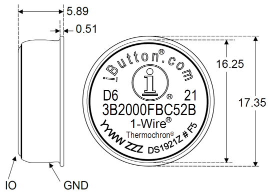

Figure 6. iButton system dimensions [27]

These sensors were selected from among several available solutions due to their technical parameters, meeting the following assumptions:

- Accuracy at least ±1°C from -30°C to +50°C;
- Temperature measurements with at least 0.5°C increments;
- Built–in Real–Time–Clock (RTC);
- Timer with accuracy at least ±2 minutes per month;
- Automated wake–up and measure with at least from 1 to 60 minutes interval;
- Logging consecutive temperature measurements in Data–log Memory;
- Recording a Long–Term Temperature Histogram with at least 2°C accuracy;
- Programmable automation in Temperature High/Low Alarm Points;
- Recording at least 24 timestamps with specified "temperature point" deviations;
- Personalized with individual NIST–Traceable Chamber;
- Complied with EN12830 standard;
- Battery–Backed memory;

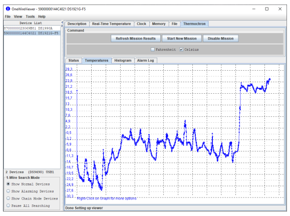

Figure 7. OneViewer application interface during data downloading

Figure 8. iButton dedicated connection cable

The measurements taken by the sensors were read from the sensors every 14 days using the dedicated OneWire Viewer (shown in Figure 7) software and the OneWire <–> USB interface (shown in Figure 8). On this basis, appropriate data summaries were prepared. The sample weekly summary [Table 2] shows the activity of a butterfly in the first time it appeared (week 10) and the last day it was seen (week 39). The temperature results were divided into two values - minimum and maximum. The values of trapped butterflies from a nearby trap were also recorded for each sensor.

3. Results and Discussion

In order to develop a national model for forecasting apple fruit activity, field studies were started and carried out in 2005 and 2006, and data from PIORIN field departments and weather stations were used. Data from local PIORIN branches covered the years 2002–2005 and came from 24 localities all over Poland. In later years, the data covered the previously obtained results. First, the value of zero for physiological development was determined. A linear regression mechanism was used for this, which takes into account 26 different exit temperatures. The best results were achieved for the threshold temperature of 10.1°C. It can therefore be concluded that the temperature of 10.0°C, reported in the literature by other researchers [28], is the threshold value of physiological development after the winter diapause for codling moth. On the basis of data from the local departments

Table 2. Table of significant weeks of the year in which the beginning and end of moth activity were observed

Week	Sensor I				Sensor II				Sensor III				Rain
	Max	AVG	Min	Flight	Max	AVG	Min	Flight	Max	AVG	Min	Flight	
10	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.70
11	3.50	-0.64	-6.00	0	0.00	0.00	0.00	0	1.75	-0.32	-3.00	0	19.40
12	16.50	3.29	-6.00	0	17.00	4.05	-4.00	0	16.75	3.67	-4.50	0	0.00
13	16.50	3.68	-5.50	0	17.50	3.75	-6.00	0	17.00	3.71	-5.75	0	0.00
14	21.00	9.98	-1.50	0	21.00	10.00	-3.00	0	21.00	9.99	-2.25	0	10.00
15	24.00	11.23	0.00	0	24.00	11.23	0.00	0	24.00	11.23	0.00	0	5.60
16	18.50	5.69	-6.88	0	18.50	6.03	-5.50	0	18.50	5.86	-5.34	0	0.20
17	21.31	9.14	-2.94	0	21.00	9.65	-2.50	0	21.16	9.40	-2.72	0	6.60
18	27.62	10.50	0.31	0	27.00	11.05	0.00	0	27.31	10.77	0.16	0	23.20
19	23.75	8.57	-2.62	0	23.50	9.05	-1.00	0	23.47	8.81	-1.81	0	24.40
20	26.50	10.97	1.63	3	25.50	11.41	0.50	2	26.00	11.19	1.06	4	12.20
21	33.00	18.48	5.63	21	33.00	18.96	4.50	19	33.00	18.72	5.06	24	0.00
22	33.63	14.67	4.94	36	33.50	15.39	5.50	39	33.56	15.03	5.22	32	1.40
23	17.63	10.65	3.88	4	19.50	11.54	4.50	2	18.56	11.10	4.19	2	18.00
24	29.13	16.96	3.81	6	29.50	17.66	4.50	4	29.31	17.31	4.16	3	17.20
25	29.38	17.21	8.44	17	29.00	17.72	6.50	14	29.19	17.46	7.47	12	12.00
26	27.62	11.92	0.00	7	26.00	12.14	0.00	8	26.81	12.03	0.00	25	0.00
27	31.88	19.72	10.00	87	29.00	19.66	7.50	101	30.44	19.69	8.81	89	2.60
28	32.56	20.79	11.63	41	30.50	20.56	8.50	38	31.53	20.67	10.06	47	10.40
29	25.94	15.47	9.81	8	24.50	15.90	8.00	6	25.22	15.69	8.91	10	14.40
30	33.75	20.40	9.13	14	34.50	20.67	9.50	21	34.13	20.53	9.31	15	8.00
31	30.75	16.57	7.50	8	27.50	16.88	8.00	8	29.13	16.73	7.75	7	44.60
32	25.44	13.36	7.19	17	22.50	13.83	6.00	16	23.97	13.60	6.59	18	5.00
33	30.31	17.40	7.31	35	25.50	16.99	5.00	37	27.69	17.19	6.16	33	4.40
34	30.75	16.85	6.63	47	28.50	16.61	5.50	54	29.34	16.73	6.31	39	0.20
35	34.38	16.51	4.19	18	32.00	15.90	1.50	18	32.19	16.20	2.84	17	0.20
36	34.62	18.44	7.00	11	29.00	18.60	7.50	11	31.81	18.52	7.25	10	0.00
37	27.00	13.01	2.50	4	27.00	13.18	0.50	3	27.00	13.09	1.50	5	7.40
38	24.88	11.39	0.00	0	23.00	10.36	-1.00	0	23.13	10.88	-0.50	0	19.20
39	24.88	9.20	0.00	0	24.90	9.09	0.00	0	24.89	9.15	0.00	0	0.20

of PIORIN, mean sums of effective temperatures for subsequent development phases were also determined. The criterion for the onset of pest activity was the date of occurrence of three consecutive days with an average daily temperature above 10°C, which is also consistent with the research conducted by Łabanowski [29].

The Table 2 contains aggregated measurement data from recorders located in an apple orchard along with data on the number of pests caught.

Based on the data collected in the Table, it can be observed that the butterflies were present when the average daily temperature exceeded the value of 10°C. This is presented by the values of the AVG column for each sensor separately. In the period up to 37–38 weeks, almost all the pests were caught, thus the number of flights after that time was zero. The data collected from the sensors allow us to use a forecasting method based on the sum effective temperature method. This method uses the correlation between the number of males caught and the sum of effective temperatures. The sum of the effective temperatures was calculated according to the modified formula proposed by Alford [30].

$$DD_{SUM} = \sum(DD_{AVG} - C_{TMP}) \tag{1}$$

where, DD_{SUM} is the sum of effective temperatures, DD_{AVG} average daily temperature, C_{TMP} life cycle limit temperature (physiological zero for given species).

The designated outlet temperature of the first individuals differs from the data from the national literature (145–155°C temperatures given by Boczek [31] and 143.2°C by Łabanowski [29]) however, it is in line with data collected by the University of California, United States [32]. The components of the average outlet temperature of individuals of the first generation range from 17.25°C to 229.05°C depending on the place and year of research. The change in the average temperature may be caused by a change in the development process of the codling moth population in Poland and by other atmospheric factors (e.g. the course of rainfall or relative air humidity).

On the basis of the collected measurement values, read from the sensors, a graph was prepared, which precisely shows the dependence of the sum of effective temperatures on the number of moths caught. This relationship is consistent not only with the results from the traps, but also with the numbers between them [Figure 10]. The effective temperature sum graphs also show the current three generations of moths that appeared in three periods of the year under study – late May, mid-July and late August.

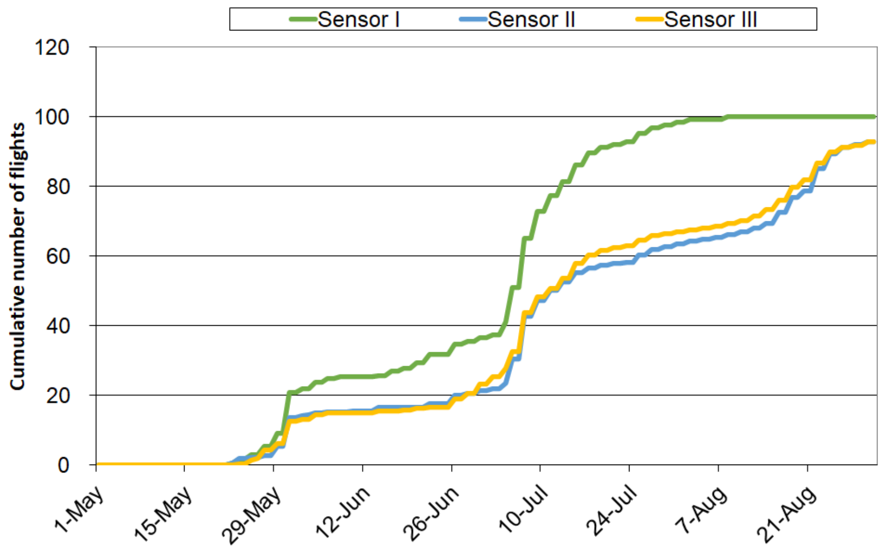

Figure 9. Codling moth activity between Sensors I–III

Since the second generation of codling moth does not always occur, the criteria for predicting it were also checked. The first criterion is the average daily temperature. According to prof. Łabanowski, if the average daily temperature in June and July is higher than 15.5°C or the maximum average in both these months is higher than 19.8°C, then the second generation of codling moth will occur. The second criterion is the sum of the effective temperatures. If the sum of these temperatures by August 1 is higher than 521.2°C or the sum in June is higher than 159.5°C, the probability of the second generation occurring is high. According to prof. Łabanowskiego [29], both criteria should be used simultaneously when forecasting the occurrence of the second generation of this pest. After analysing the data collected in the years 2002–2005, it turned out that the criterion based on the sum of effective temperatures is less accurate. Out of 46 analysed examples, as many as 11 cases gave an incorrect result. However, the simultaneous use of both criteria gave the correct result.

In the years 2005–2006, field tests were carried out in an apple orchard near Tarczyn to describe the activity of codling moths. Temperature recorders were used to measure the temperature, suspended in the treetops at the height of 1.8 [m] in the quarters where the activity of butterflies was monitored. Moth activity is presented in the chart 9. Temperatures were recorded every 15 minutes to two decimal places. The average daily temperature was calculated based on the whole day's results. In this way, the temperature conditions that prevail in the place of the pest's occurrence were checked. Moth activity was monitored with pheromone traps and caught butterflies were counted every two days simultaneously.

In 2005, the first moth were caught on May 21 – the sum of effective temperatures was 58.89°C (17 days with the temperature above 10°C). In 2006, the first butterflies were caught on May 5 – total effective temperatures was 63.14°C (similar to 2005 – 17 days with the temperature above 10°C). Using the dependence determined by prof. Łabanowski, the theoretical temperature of the apple fruit outlet was calculated and the values were 68.36°C and 72.39°C, respectively. In both years, the difference between the actual outlet temperature and the theoretically calculated values was approx. 10°C. This difference could result from the variability of the pest population and the method of temperature recording – the own research recorded the temperature in field conditions, while prof. Łabanowski used meteorological stations for measurements.

The relationship for the butterfly activity results in the study period for each sensor individually can be seen in [Figure 9]. It can also be noticed that the coverage of the orchard with butterflies, despite the considerable distance from the traps and the span of the area in the Quarter itself, did not disturb the even distribution of pests. One can also add that the butterflies in the second generation are three times more than the first, which appeared in the orchard at the beginning of May. It also may suggest less effective prevention of their dispersal or a late reaction concerning the emergence and the chance of egg-laying, the effect of which is seen in the growth of the second generation. Such growth of butterflies increases the risk of crop damage by subsequent pests. During the research, regular spraying was carried out to protect the orchard and verify the effectiveness of the currently operating systems based on area temperature measurements carried out by PIORIN stations.

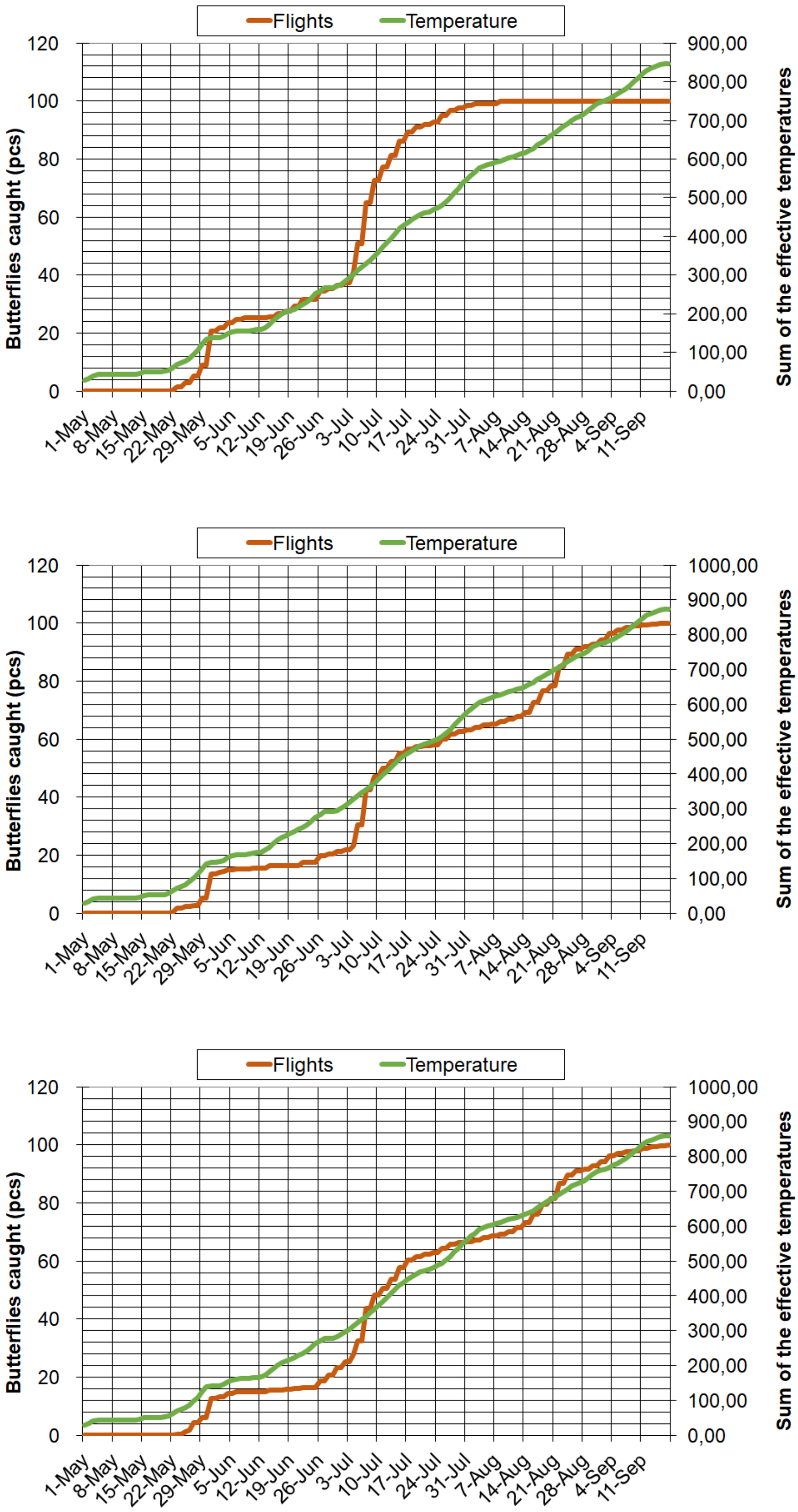

Figure 10. Sum of effective temperatures and butterflies caught (top to bottom: Sensor I, Sensor II, Sensor III)

This effect can also be seen in the activity graph compared to three sensors simultaneously [Figure 11]. In the same period, the results of the caught moths were collected for each area covered by the sensor.

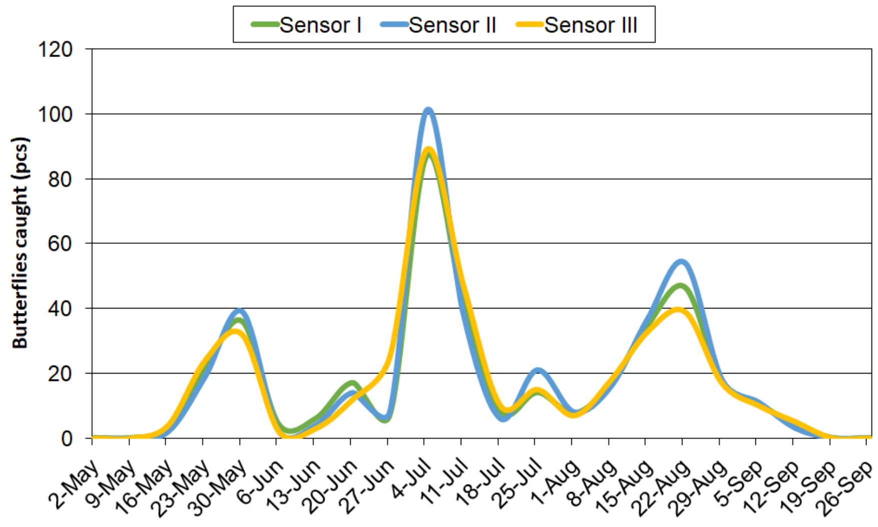

Figure 11. Relation between butterflies caught in each sensor area in time

By monitoring the average daily temperatures, the growth rate of the moths in the study area can also be verified, e.g. "speed of development" or "growth rate" by egg laying and hatching. Based on Figure 12, it can be concluded that a temperature increase of 4°C causes an increase in the aforementioned "speed" factor of almost 500%. It also follows that such a slight increase in temperature, combined with a delay in response to the phenomenon of pest activity, can cause cumulatively huge losses.

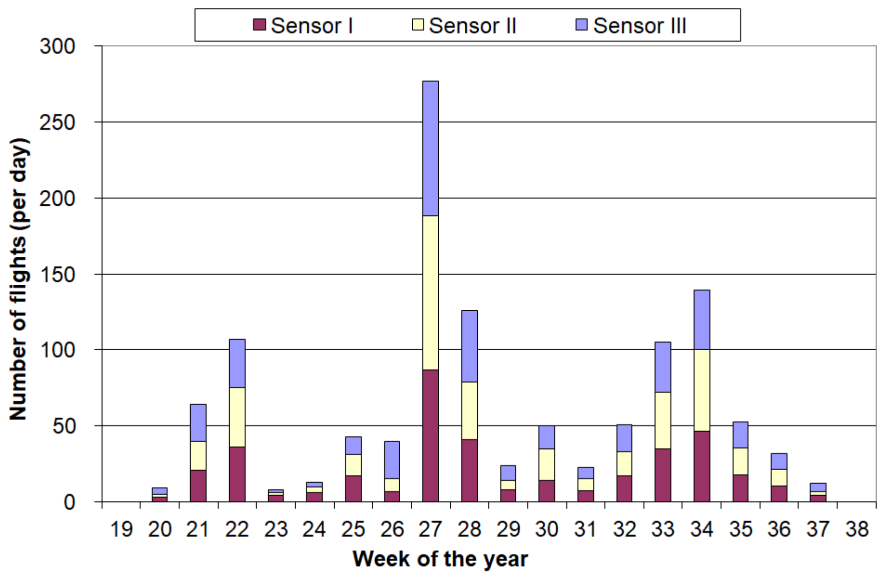

Figure 12. Daily number of flights during observation period

One of the last factors examined during the research measurements was the influence of relative humidity in a given area on the pest activity coefficient was also noticed. When there was rainfall, despite favourable temperature conditions, the butterfly population was smaller. This effect is presented in the diagram [Figure 13]. It is related to the country itself. Poland is an area with a temperate, warm, transitional climate. Only a few warm precipitation days can be observed in spring and late spring. And this, in turn, favours the first generation to fly. The leading factor here is the cumulative average temperature for the whole day. It is only at the beginning of June that rainfall increases can be observed, which stops the development of the second generation and its departure. Since moisture alone is not a significant factor in monitoring butterflies, it becomes necessary to relate one biological parameter to another – temperature.

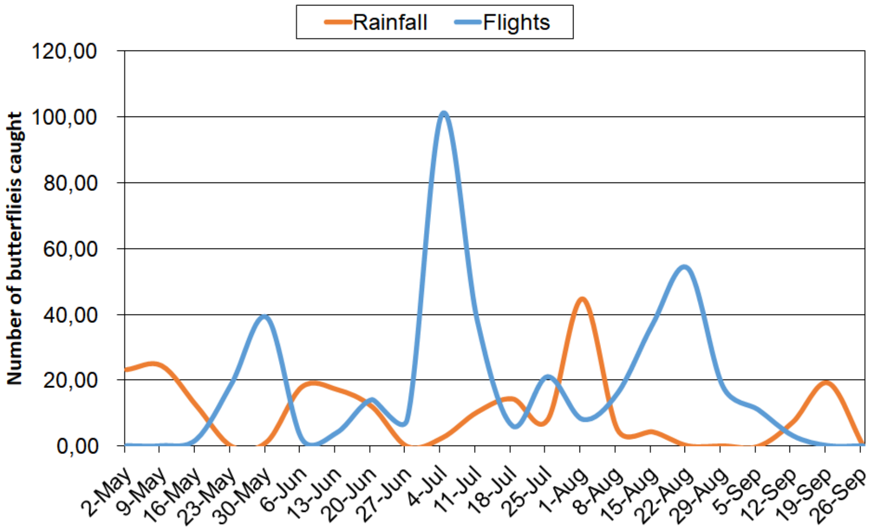

Figure 13. Relation between rainfall and butterflies caught

4. Conclusions

Currently, two methods are used to reduce the development of Codling moths in Polish (and not only) orchards. They are based on measurement (predictive) methods publicly offered in PIORIN messages for a given region or local methods using pheromone traps. For horticulture, the use of both methods at the same time is almost necessary to minimize the damage that can be caused by a butterfly in the event of neglecting its activity during the flight period. From the point of view of fruit growers, using only the first method quite imprecisely indicates the date and date of the suggested spraying activities, which cannot be economically viable due to potential losses. Controlling this process with the second method would require many independent measurements. Above all, however, due to the extent of orchard areas, it would be time-consuming and functioning in this form is also not economical. Currently used local methods based on traps are implemented on a much smaller scale. This also introduces measurement errors and can negatively affect the effectiveness of the protection.

The measurement studies conducted in recent years and carried out in parallel have shown the repeatability of results and a strong dependence of the measurement values performed locally, analogous to those provided by the National Institute of National Remembrance for the entire region, on the numbers of butterflies in each of the three generations. Such a solution affects more accurate results and the chance of more effective pest control.

The conducted research allows considering the method based on using sensors directly in the production orchard as a fully effective method. Protective agrochemical treatments, which limit the population size of the codling moth, should be carried out during the departure period of approx. 50% of individuals of a given generation. The presented research shows that protection treatments should be performed: for the first generation of the pest – when the sum of effective temperatures amounts to approx. 253°C – it corresponds to the departure of approx. 50% of the first generation individuals; for the second generation (summer) – when the sum of temperatures amounts to approx. 670°C which corresponds to the departure of approx. 50% of the second generation specimens.

The dynamics of flights, apart from temperature, are also influenced by other atmospheric factors. The intensity of precipitation plays a particularly important role.

With high rainfall, the activity of moths drops significantly. Summarizing the results of the conducted research and statistical calculations, the sum of effective temperatures is a promising signalling method. It complements the signalling using pheromone traps and can also be used as an independent forecasting method, allowing for forecasting the date of departure based on the temperature forecast in the coming days. Therefore, a very important advantage of this mechanism is the ability to forecast the pest's occurrence in advance.

Based on the collected data and the results achieved during the last years of research, it is natural to prepare a mobile monitoring system in IoT technology. Local and dense distribution of sensors will allow for precise determination of local climatic zones. This, in turn, will make it possible to determine with greater probability the susceptibility to butterfly escape in such an area concerning other parts of the orchard. Determining the date and region in which it will be necessary to carry out the spraying operation is the most optimal, economical and effective solution for orchards to reduce losses caused by the pest.

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