

## EVALUATING EFFICIENCY OF SMART ACOUSTIC SYSTEM FOR PROTECTION OF APPLE ORCHARDS AGAINST PESTS

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**Abstract.** The paper presents evaluation of the efficiency of an intelligent acoustic system, equipped with motion sensors, intended for the protection of apple orchards against birds. The study was conducted over a period of 45 days (May-June 2025) in an orchard in the Bucharest-Băneasa area, monitoring the environmental parameters and behavior of common birds (starlings, crows, thrushes, blackbirds, sparrows, wild pigeons, and jays). The system operated in two complementary modes: a random mode, in which noises are randomly generated by PLC to prevent bird habituation, and a mode based on PIR sensors, activating sounds immediately upon motion detection. The analysis revealed that the type of sound, the distance from the device, the weather conditions, and the size of bird groups influence the efficiency of the system. Diurnal predator sounds (hawk, falcon) showed higher efficiency (80-91%) compared to nocturnal predator sounds (owl, 55-79%). During the monitoring, the overall average efficiency of the system was 72.47%, with a standard deviation of  $\pm 12.49\%$ , ranging between 55% and 91%. The maximum values were obtained in conditions of a low number of birds and greater distances from the device, while the minimum values were associated with large groups of birds and repetitive use of the same signals. The results confirm that the system is effective as a preventive method and emphasize the importance of alternating types of sounds and adapting to weather conditions to prevent bird habituation. This study demonstrates the applicability of an intelligent acoustic system in the protection of apple orchards and provides the basis for integration with other anti-bird technologies to increase performance in real operating conditions.

**Keywords:** apple orchard protection, intelligent acoustic systems, motion sensors, preventive agriculture technology.

### Introduction

Agroecosystems are characterized by complex interactions between living organisms and environmental factors, and birds are an important element of these systems. Numerous studies have highlighted the fact that birds can provide essential ecosystem services, in particular by reducing crop pest populations [1-4]. At the same time, certain species can cause significant economic losses in horticultural crops, especially in orchards and fruit plantations, where consumption or damage to fruit reduces the quantity and quality of marketable production [5].

To limit this damage, farmers use various deterrent methods, including visual, mechanical and acoustic solutions. Among these, acoustic systems are frequently used because they can cover large areas and trigger rapid avoidance responses in birds [6]. However, the effectiveness of these devices depends on the characteristics of the sound signals and environmental conditions. Studies show that high-frequency and high-amplitude sounds can increase the effectiveness of deterrent methods, as they more strongly stimulate the natural anti-predator response mechanisms of birds [7]. Also, the range and performance of acoustic devices can vary depending on the type of equipment and field conditions [8].

The response of birds to sound signals is closely linked to their natural communication mechanisms. Birds frequently use alarm vocalizations to warn other individuals of the presence of danger, which can trigger collective responses to avoid or attack the intruder [9]. At the same time, behavioural responses can be influenced by ambient noise, the ecological context, or the birds' habituation to certain acoustic signals [10; 11].

In the context of climate change and changing environmental conditions, the interactions between birds, pests and agricultural crops may undergo significant changes, which may influence the effectiveness of wildlife management strategies in agroecosystems [12].

Therefore, evaluating the performance of bird deterrent systems under real field conditions is essential for the development of effective and sustainable methods for the protection of horticultural crops.

In this context, the objective of this study was to evaluate the effectiveness of an intelligent acoustic bird repellent system used in an apple orchard, as well as to analyse the behavioural reactions of birds and the factors that may influence the effectiveness of this protection system.

## Materials and methods

The study was conducted in an apple orchard, under real agricultural exploitation conditions. Monitoring was carried out daily, for 45 days, throughout the experimental period, by observing the reaction of the birds after activating the system. The intelligent acoustic bird scaring system was designed to reduce the pressure of harmful birds on the crop. The system was composed of the following modules.

1. Detection mode: PIR motion sensors with a detection range of up to 7 meters.
  2. Behavioural response of birds and system efficiency were assessed within a broader observation range of approximately 25-100 m, depending on environmental conditions and visibility; intelligent analysis mode to confirm the presence of birds; central controller.
  3. Acoustic rejection mode: sonic generator for playing predator sounds (falcon, hawk, owl) with acoustic power between 105-110 dB at 1 m.
  4. Power module: autonomous solar module, consisting of a solar panel and 12V DC storage batteries.
- The entire system was mounted on a metal frame, made of square pipes and steel sheets for structural stability and protection against environmental factors.

The operational flow chart of the acoustic system is shown in Figure 1. After power-up, the control unit manages the selection of the operating mode, timings, sensor reading and activation of the acoustic system. In random mode, it generates a random waiting interval (5-30 minutes) before activation. In PIR sensor mode, the control unit continuously monitors the sensors and immediately activates the system upon detection of motion. After each 40-second activation cycle, the control unit stops the system and resumes monitoring, ensuring autonomous and adaptive operation. The system operated in an event-triggered mode, with an average of 5-15 activations per day, depending on bird presence and the activity level.

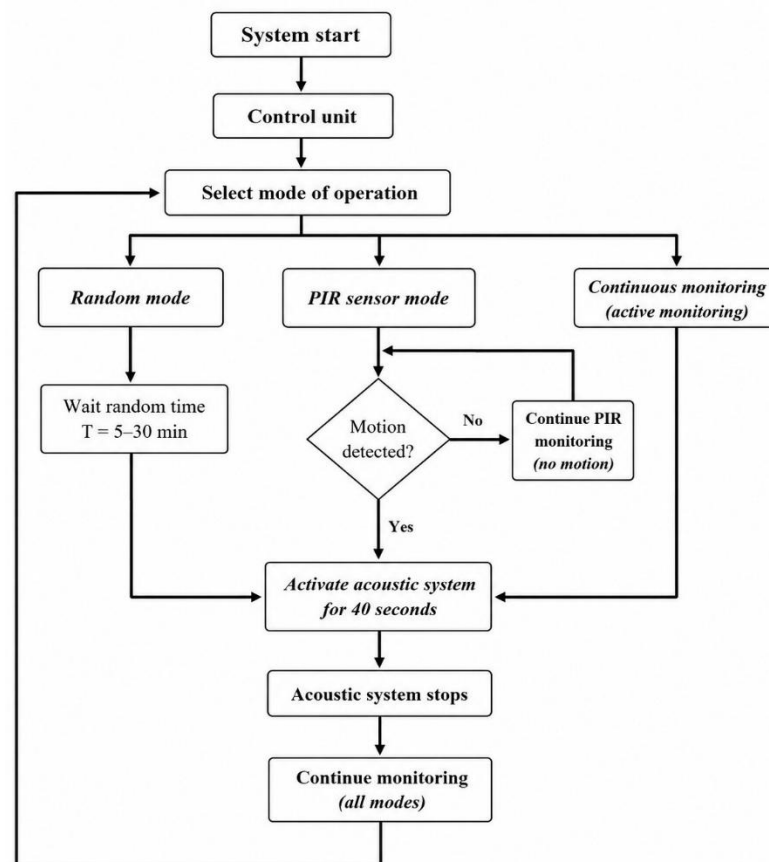


Fig. 1. Operational flow chart of the acoustic bird scaring system

The efficiency of the system was assessed daily, based on the reaction of the birds after the activation of the acoustic stimuli. Observations were made daily at 10:00, over 45 days (May-June), recording the following parameters: number of birds observed; type of birds; type of sound activated; duration of the sound (minutes); distance from the device (m); estimated noise level (dB); meteorological conditions; qualitative observations (moderate reaction or “persistent birds” in the area).

The estimated efficiency of the system was determined daily by visual observation, based on the reaction of the birds to the acoustic stimuli, using a qualitative scale from < 60% (persistent birds ignoring the sound) to > 90% (birds immediately leaving the area). The values obtained were classified into three categories: low efficiency (< 60%), medium (60-80%) and high (> 80%).

## Results and discussion

The results show: the evolution over time of the efficiency of the acoustic system and the relationship between the number of birds, the performance of each sound (falcone, hawk, owl) used to scare away harmful birds, the correlation between distance, noise and efficiency, the influence of weather conditions, the correlation matrix between variables. Figure 2 shows the temporal evolution of the efficiency of the acoustic system and the number of birds observed daily during the 45 days of monitoring (May-June) in the apple orchard.

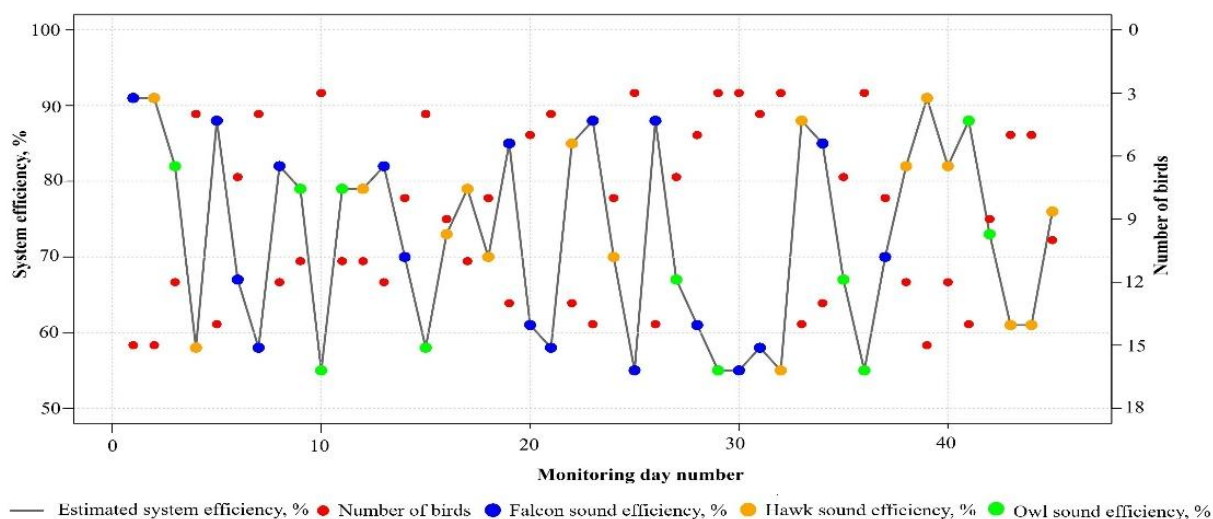


Fig. 2. Temporal evolution of the efficiency of the acoustic system and the presence of birds, with differentiation by sound types

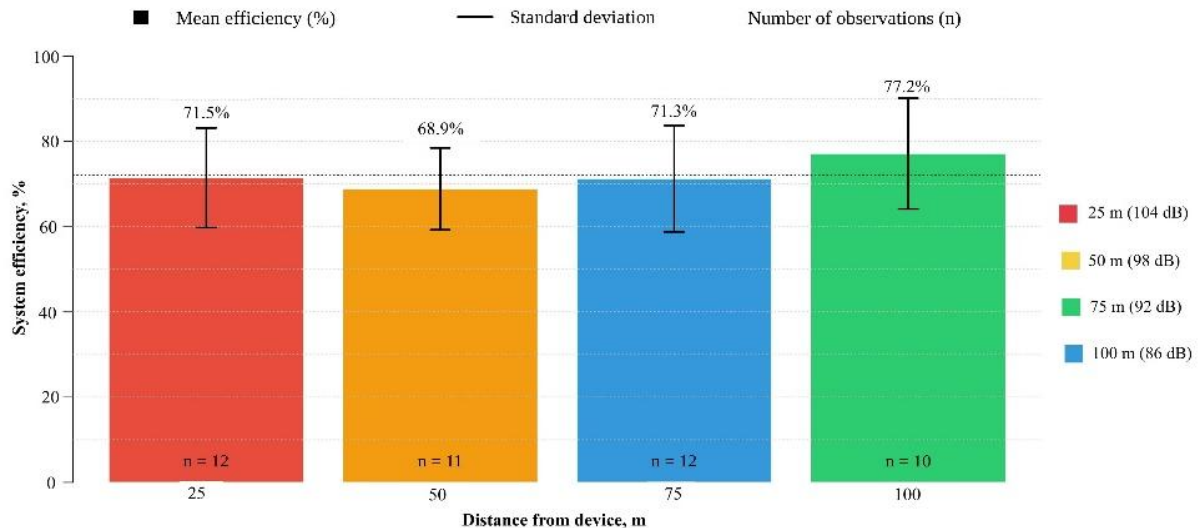
It can be seen from Figure 2 that there is a negative correlation between the number of birds and the estimated efficiency of the acoustic system, on days with a high number of birds, the efficiency tends to be lower. On days 4, 7, 10, 15, 21, 25, 29-32 and 36, when the number of birds exceeded 12, the efficiency dropped below 60%, with observations of “persistent birds” being recorded [6; 8]. The overall average of the estimated efficiency over the entire period was  $72.47\% \pm 12.49$ , with minimum and maximum values in the range of 55-91%. After day 25, the frequency of days with efficiency < 60% increased significantly, indicating the onset of habituation.

Analysis of bird numbers showed an average number of 9 birds/day, with ranges between a minimum of 3 and a maximum of 15 birds, days with 3-6 birds generally had efficiencies of 82-91%, and days with 13-15 birds had reduced efficiencies of 55-61%.

The comparative analysis of the effectiveness according to the type of sound, also shown in Figure 2, highlights the fact that the diurnal predator signals (falcone and hawk) generated superior efficiencies compared to the owl sound. The average efficiency of the hawk sound ( $74.2\% \pm 11.2$ ), observed in 16 days, had the best overall performance of the 45 monitored days, closely followed by the efficiency of the falcone sound ( $73.2\% \pm 13.7$ ), observed in 18 days, while the efficiency of the owl sound ( $68.9\% \pm 11.9$ ), observed in 11 days, had the lowest performance. Although the hawk sound proved to be slightly more effective than the others, no type of sound manages to maintain a high efficiency in the long term in the absence of complementary measures to combat habituation [6; 8]. These results

highlight the need to implement adaptive strategies that combine acoustic stimuli with visual methods, more frequent sound rotation, and, where possible, active chasing to delay the onset of habituation and maintain the effectiveness of the system in the long term [2; 5; 12].

Figure 3 shows the average efficiency of the acoustic system as a function of the distance and sound pressure level.



**Fig. 3. Distribution of acoustic system efficiency depending on the distance and sound pressure level**

An unexpected increase in efficiency with increasing distance is observed. The highest efficiency was recorded at 100 m (77.2%), although here the noise level was the lowest (86 dB). At the opposite pole, the lowest efficiency was recorded at 50 m (68.9%), with an intermediate noise level (98 dB). This result can be explained by the differentiated distribution of bird species in the orchard [6; 10]: more persistent species (crows, pigeons) were more frequent in the central areas (25-50 m), while more sensitive species (blackbirds, thrushes) dominated the peripheral area (75-100 m). It was shown in the paper [7] that the efficiency of deterrence depends more on the characteristics of the sound reported to the target species than on its absolute intensity.

Regarding the variability of efficiency (standard deviation), it was maximum at 100 m ( $\pm 13.0$ ) and minimum at 50 m ( $\pm 9.6$ ), indicating a lower predictability of the system at long distances, but a higher chance of success in favorable conditions. Therefore, for optimal protection, it is recommended to place the system so as to cover primarily peripheral areas (75-100 m), and in central areas (25-50 m) to use complementary methods (visual scares, more aggressive rotation of sounds) to counteract bird persistence [7; 12].

Weather conditions partially influenced the system efficiency: fog and moderate wind slightly reduced the propagation of sound waves, while cloudy or partly cloudy skies had no significant impact. In sunny weather, the birds' reaction was faster, probably due to increased visibility and activity. Thus, weather factors can moderate sound propagation and bird behavior, generating variations in efficiency [9; 11].

The dominant species observed of harmful birds in the apple orchard were: crows, thrushes, sparrows, wild pigeons, starlings, blackbirds, jays. Of these, the most difficult to drive away harmful bird species were: crows, starlings, pigeons. At the same time, the most sensitive to sounds were: thrushes, blackbirds and sparrows.

The correlation matrix shown in Figure 4 highlights the linear relationships between the variables measured in the study (distance, acoustic system efficiency, sound duration, noise level, monitored day and number of birds), providing an overview of the factors that influence the efficiency of the acoustic system.

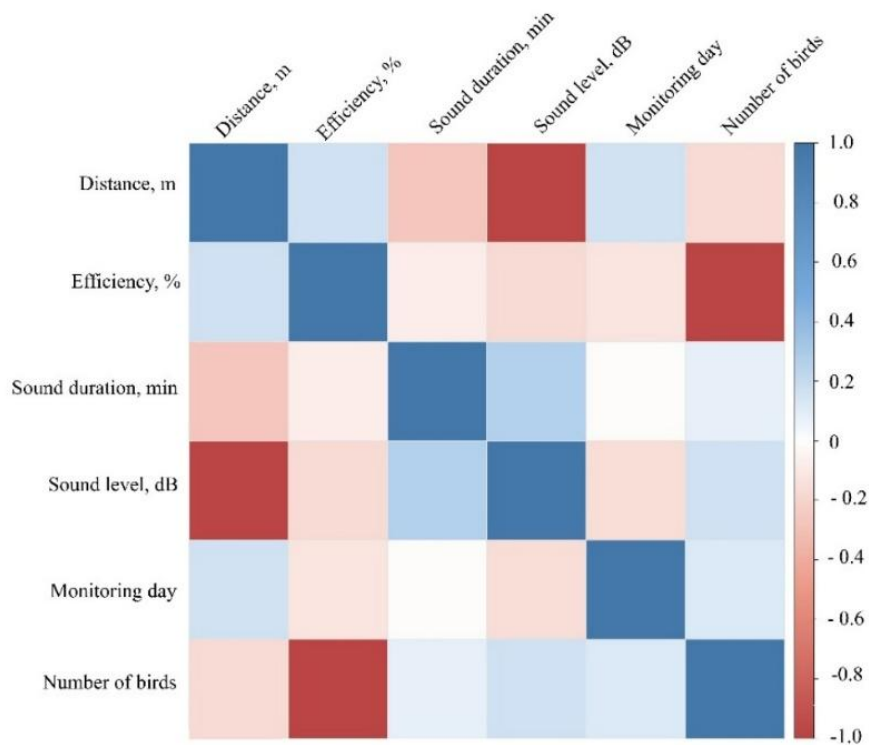


Fig. 4 Correlation matrix of acoustic system variables

The strongest positive correlation was between the distance and noise level ( $r = -0.99$ ). This strongly negative relationship was expected because, according to the laws of physics, sound intensity decreases with increasing the distance from the source. In the present study, the noise level decreased from 104 dB at 25 m to 86 dB at 100 m, confirming the natural attenuation of sound in open fields [7].

Another significant positive correlation is observed between the number of birds and the monitoring day ( $r = 0.28$ ). Although the value is moderate, it suggests a trend of increasing bird numbers during the study period, due to the establishment of habituation and the return of birds to the orchard [5].

The most important negative correlation for the study objective is that between the number of birds and efficiency ( $r = -0.42$ ). This result confirms that, as the number of birds present in the orchard increases, the system ability to drive them away decreases significantly. This phenomenon can be explained by flocking behavior and by the fact that persistent species (crows, pigeons), frequently appear in large groups [6]. A negative correlation is also observed between duration and efficiency ( $r = -0.14$ ), although the value is small. This suggests that longer sound duration does not necessarily improve efficiency, and in some cases may even contribute to habituation [8].

The correlation between the monitoring day and efficiency ( $r = -0.13$ ) confirms the decreasing trend of efficiency over time, highlighting the gradual establishment of habituation. Although the value is not very strong, it supports the qualitative observations regarding the increase in the frequency of days with persistent birds in the second half of the study period [6,8].

The correlation between the distance and efficiency ( $r = 0.17$ ) is weakly positive, indicating that, in the overall data, efficiency tends to be slightly higher at longer distances. This result is due to the differential distribution of bird species in the orchard [7].

The correlation analysis highlights several essential aspects for optimizing the acoustic system.

- Monitoring the number of birds is essential, as the negative correlation with efficiency ( $r = -0.42$ ) shows that the presence of large groups significantly reduces the efficiency. The system should be able to detect and respond differentially depending on the number of birds.
- Habituation over time is confirmed by the negative correlation between the day and efficiency ( $r = -0.13$ ), although the modest value suggests that other factors (species, weather conditions) also play an important role.
- Sound duration does not seem to be a critical factor ( $r = -0.14$  with efficiency), indicating that resources should not be directed towards increasing duration, but towards diversifying stimuli.

- The distance-efficiency relationship ( $r = 0.17$ ) recommends a nuanced approach to system placement, taking into account the target species in each area of the orchard.

Compared to airport bird deterrent systems, which rely on complex integrated technologies, the proposed system provides a cost-effective and efficient solution for agricultural applications.

## Conclusions

The following conclusions were drawn from the present study.

1. The acoustic crop protection system significantly reduces the presence of birds in the apple orchard, with an average efficiency of 72.47%.
2. The results highlight a significant negative correlation between the number of birds and efficiency ( $r = -0.42$ ), confirming that large groups are more difficult to drive away.
3. A habituation trend was observed over time, reflected by the gradual decrease in efficiency and the increase in the frequency of days with “persistent birds” in the second half of the study period.
4. The maximum efficiency was at 100 m (77.2%), influenced by the distribution of species in the orchard.
5. The more sensitive species (blackbirds, thrushes) predominate in peripheral areas, while the more persistent species (crows, pigeons) are concentrated in central areas.
6. The falcon sound proved to be the most effective (74.2%), closely followed by the peregrine falcon (73.2%), while the owl sound (68.9%) had significantly lower performance during the day.
7. The efficiency of the acoustic system was determined by three categories of factors: biological (bird density, presence of gregarious species), technical (sound type, distance) and environmental (weather conditions).
8. The system operates stably between 25-100 m, with the sound type and distance having a lower impact.
9. The efficiency decreases in conditions of high density, gregarious species (starlings, crows) and adverse weather (wind, fog).
10. The system is viable, but requires anti-habituation strategies (sound rotation, combined methods and adaptation of operating parameters depending on the target species and environmental context).
11. Future research should explore multivariate models that integrate both quantitative and qualitative variables (bird species), for better prediction of pest bird removal from crops.

## Acknowledgements

The paper has been funded by the Program NUCLEU 2023-2026, PN 23 04 01 06 “Intelligent mixed system for protection of agricultural crops against pests according to the Agriculture Concept 4.0”, Contract no. 9N/01.01.2023.

## Author contributions:

Conceptualization, P.A.; methodology, P.A. and I.A.; software, I.A.; validation, P.A.; formal analysis, P.A.; investigation, I.A. and S.G.; data curation, I.A. and S.G.; writing – original draft preparation, P.A.; writing – review and editing, I.A. and S.G.; visualization, P.A., I.A. and S.G.; project administration, P.A.; funding acquisition, P.A. All authors have read and agreed to the published version of the manuscript.

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