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Effect of temperature on the migration of the Sunn pest *Eurygaster maura* L. 1758 (Hemiptera: Scutelleridae) from overwintering area

Süne, *Eurygaster maura* L. 1758 (Hemiptera: Scutelleridae)'nın kışlaktan göç seyrine sıcaklığın etkisi

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A B S T R A C T

Sunn pest (*Eurygaster* spp.) is one of the most important pests adversely affecting the yield and quality of wheat, which is one of the main nutritional products for humans. In controlling the sunn pest, determining the migration pattern of the pest from its overwintering sites to wheat fields is of critical importance. The ability to predict the onset and end of this migration event forms the basis of forecasting and warning systems for controlling the sunn pest. In this study, conducted over four life cycles from 2014 to 2018 in two wintering sites, the predictability of the onset and end of the sunn pest's migration from wintering sites to wheat fields using temperature data was investigated. The obtained data were evaluated using pure temperature values, the day-degree model using effective temperature sums, and machine learning (decision tree) methods using cumulative temperature values. The study revealed that the migration pattern of the sunn pest cannot be explained solely by temperature data.

INTRODUCTION

Sunn pest (*Eurygaster* spp.) is one of the pests causing economic losses in wheat in the Middle East, Eastern and Northeastern Europe, and Africa (Critchley 1998). Both adult and nymph stages of the sunn pest pierce and suck wheat grains during various phenological stages, resulting in significant losses in germination capacity as well as bread and pasta-making qualities. Failure to control the pest in places and years with high infestation can lead to up to 100% loss in terms of both quality and quantity (Anonymous 2008, Özkan et al. 2017).

The pest, which reproduces once a year, has an active and passive phase in its life cycle. It spends approximately 8-9 months in a passive phase called overwintered site in the mountains. Pests that have hibernated spend the spring flying from the mountains to wheat fields in the plains. The passive period ends and the active period begin with the start of flights to the plains. Upon reaching the plains, overwintered adults feed, mate, and lay their eggs for 1.5-2 months. At the end of this period, adults die. The eggs hatch within 2-3 weeks depending on climatic conditions, and nymphs emerge. Nymphs that go through 5 instars within an average of 1 month become the new generation adults (NGA). The new generation of adults feed voraciously, store the necessary energy, and retreat to their overwintering areas with the harvest. The passive phase consists of two periods: the post-harvest period, from July (after harvest) until October-November, known as the summering period; and the period from October-November to March-April of the following year, known as the overwintering period.

Sunn pest control, carried out within the framework of integrated control principles, is mainly based on chemical control. The annual pest control season begins with the spring wintering survey, in which the population density of overwintered adults (OA) that can land from wintering places to grain areas is determined. Following the spring wintering survey, the first movements, that is the first descents, are detected to determine the migration of overwintered adults from the wintering sites to the plains. This event marks the first critical point in pest control and is referred to as the onset of descents. The second critical point is the commencement of the survey to determine the density and distribution of OA pests in wheat cultivation areas. For this purpose, the completion of the descent of 95% of OA pest populations from overwintered sites to the plains is determined (termination of descents). As is evident, in pest control, determining two critical biological points – the onset and termination of descent – is crucial. In predictive warning studies conducted by various researchers on combating pests, these two critical points, which are important to determine, have generally been attempted to be predicted by associating them only with temperature values (Agacino 1972, Aleksandrov 1949, Amir-Maafi et al. 2007, Arkhangel'skii 1939, Barbulescu 1967, 1971, Duman 2015, Gözüaçık et al. 2016, Grigorov and Gospodinov 1964, Ionescu and Mustatea 1975, İleri 1957, İslamoğlu 2010, Karaca et al. 2009, Kılıç and Karslıoğlu 1961, Kiliç 1978, Lodos 1961, Lazarov et al. 1969, Memişoğlu 1985, Mozaffari and Azizian 2011, Nakova and Urukov 1976, Öncüer and Kıvan 1995, Paulian and Popov 1980, Peredelskii et al. 1951, Popov and Barbulescu 1978, Silvestri 1934, Smolyannikov 1955, Tafaghodinia and Majdabadi 2006, Vojdani 1954, Yüksel and Bayseç 1964). In this study, the explicability of the migration pattern from the overwintering sites, which is critical in combating pests, was investigated solely based on temperature values.

MATERIALS AND METHODS

The studies were conducted in the wintering sites of Kırşehir-Hasanpaşa hill (wintering plants: hedgehog-vetch, hedgehog herb, thyme, oregano) and Aksaray-Ekecik mountain (wintering plant: oak) from 2014 to 2018, characterized by high population density of pests and different wintering plants. In both overwintering sites, the sunn pest population was overwhelmingly dominated by the species *Eurygaster maura*, accounting for 99.5% of the total. Koçak and Babaroğlu (2005) also reported that *E. maura* comprised 99.5% of the population in the aforementioned overwintering sites. To obtain temperature data, a meteorological station (IMetos) was installed at each wintering site.

To determine the main critical points for control, the life cycle critical periods of the pest were considered and divided into three phases: Phase 1: It covers approximately an 8-9 month period, starting with the movement of the new generation of adults to the overwintering sites following the completion of wheat harvest and ending with the first movements of overwintered adult sunn pests in spring at the overwintering grounds. This period, which is the sum of the summer dormancy (estivation) and winter dormancy (hibernation) periods, is also referred to as the passive period. Phase 2: It includes the period from the initial movement of overwintered adult sunn pests in spring to the completion of the descent of 95% of the adult population in the wintering site. Phase 3: This phase, also known as the active period, begins with the completion of the descent of 95% of the overwintered adult population in the wintering site and ends with the time spent in the field until the new generation of adult's moves to the wintering site after the completion of wheat harvesting. In Phase 1, covering the passive period, just before the initial movement of the sunn pests in the wintering site, the sunn pest densities in both wintering sites were determined (spring wintering site census).

Following the spring wintering site survey, the wintering sites were checked every 2-3 days to determine the first movements of the sunn pests. Counting continued until 95% of the sunn pest population in the wintering site had completed its descent after the detection of the initial movement of the sunn pests.

Counts in the wintering sites were conducted according to the type of vegetation cover. If the vegetation cover consisted of plants such as oak or pine, 32 counts were conducted using 1/16 m^2 (25x25 cm) frames to determine the number of individuals under fallen leaves. If the vegetation cover consists of plants such as coneflower, milkvetch, and thyme, counts were conducted taking into account the plant numbers in Table 1 (Dörtbudak et al. 1991).

The predictability of the start and completion times of the migration of overwintered adults from wintering sites to wheat fields based on temperature values has been

Table 1. Basis plant sizes and corresponding plant numbers per m^2 for small, medium, and large categories in wintering area plants

Plant grub	Vegetation					
	Coneflower		Coneflower-Milkvetch		Thyme	
	Diameter (cm) (narrowest X largest)	Number of plants in m^2	Diameter (cm) (narrowest X largest)	Number of plants in m^2	Diameter (cm) (narrowest X largest)	Number of plants in m^2
Small	20x30	17	20x30	26	20x27	26
Medium	31x40	9	31x50	8	28x35	14
Big	41<	3	51<	8	36x60	8

investigated using three different methods, which are crucial points in the execution of pest control.

1- The daily average, minimum, and maximum temperatures from January 1st until the start and end of the migration were evaluated without undergoing any processing. The logistic regression method was utilized for the evaluations.

2- Forecast warning models based on the calculation of the total daily average temperatures above the development threshold (degree-days) were investigated to determine the start and end times of descents from the wintering sites. In degree-day calculations, two different starting points were used, including the beginning of Phase 1, and the average calculation method [Effective temperature sum = (maximum temperature + minimum temperature)/2) - development threshold] was used. Various researchers used different development threshold temperatures (0-20 °C) in the calculations of the effective temperature sum method, which is utilized in the forecast warning studies for pests. In this study, commonly used development threshold values of >0 °C and >10 °C were adopted for the calculations related to effective temperature sums (Amir-Maafi et al. 2007, Ionescu and Mustatea 1975, Paulian and Barbulescu 1970, Popov and Barbulescu 1978). The nominal logistic regression method was used in the evaluations.

3- Artificial intelligence, machine learning, and data mining techniques have been utilized to predict the start and end times of descent from wintering sites with minimal error, based on the relationships between temperature values and the onset of the sunn pest biological events. Decision tree models have been developed to predict pest migration onset and completion times from wintering sites.

For this purpose, measurement and label data were collected during the studies conducted between 2014 and 2018. Measurement data consisted of temperature values (average, minimum, maximum), including date and location information. Accumulative measurements of values above 0 °C throughout each life cycle of the pest were calculated from the values directly measured periodically by the sensors. Label data, primarily collected through field studies under natural conditions, mainly consists of phase information for all days.

During the study, models were developed using a dataset consisting of 2925 daily records for 2 regions and 4 life cycles each. Since there was no separate dataset available for testing the models, they were evaluated using a 10-fold cross-validation method.

Statistical Analyses were performed using SPSS 21 statistical software (IBM Corp. 2021). For phase estimation, decision tree algorithms integrated into the WEKA software package were utilized (Bouckaert et al. 2016).

RESULTS AND DISCUSSION

Pure temperature values

According to researchers, climatic conditions, especially temperature, play a significant role in the initiation and continuation of descent from wintering sites, with various threshold values (10-25 °C). Therefore, the effect of temperature on the initial movement and descent pattern of the pests in the wintering sites was investigated during the four life cycles studied (2014-2018). The first critical point for pest control, the start of sunn pest descents from wintering sites, occurred on different dates from year to year during the study period, but it consistently took place in April in both wintering sites (Table 2). In both wintering sites, descents typically begin when the maximum temperature in the wintering site rises above 10 °C (ranging from 9.2 °C to 20 °C). However, it was determined that, despite occasional rises in temperature in the days leading up to the onset of migration, there was no movement observed in the overwintered adults.

The effect of daily average, minimum, and maximum temperatures on the onset of migration and the descent pattern of the pest in the wintering area is provided (Table 3). The general trend indicates that both average and

Table 2. Descent pattern of overwintered adult sunn pest populations from the Ekecik mountain (Aksaray) and Hasanpaşa hill (Kırşehir) wintering sites from 2014 to 2018

Wintering site	Stage	Phase cycle	Status	Life cycle			
				Cycle 1	Cycle 2	Cycle 3	Cycle 4
				2014-2015	2015-2016	2016-2017	2017-2018
Kırşehir Hasanpaşa hill	Passive period	$Phase_1$	Beginning	21.7.2014	30.7.2015	26.7.2016	27.7.2017
			Ending	28.4.2015	8.4.2016	20.4.2017	5.4.2018
			Time	274 day	258 day	270 day	254 day
		$Phase_2$	Beginning	29.4.2015	9.4.2016	21.4.2017	9.4.2018
			Ending	8.5.2015	25.4.2016	4.5.2017	19.4.2018
			Time	10 day	17 day	14 day	10 day
	Active period	$Phase_3$	Beginning	9.5.2015	26.4.2016	5.5.2017	20.4.2018
			Ending	29.7.2015	25.7.2016	26.7.2017	
			Time	81 day	90 day	81 day	
Aksaray Ekecik mountain	Passive period	$Phase_1$	Beginning	21.7.2014	30.7.2015	16.7.2016	19.7.2017
			Ending	28.4.2015	6.4.2016	20.4.2017	5.4.2018
			Time	273 day	263 day	277 day	259 day
		$Phase_2$	Beginning	29.4.2015	7.4.2016	21.4.2017	9.4.2018
			Ending	8.5.2015	22.4.2016	2.5.2017	19.4.2018
			Time	10 day	18 day	12 day	10 day
	Active period	$Phase_3$	Beginning	9.5.2015	23.4.2016	3.5.2017	20.4.2018
			Ending	29.7.2015	15.7.2016	18.7.2017	
			Time	82 day	84 day	76 day	

Table 3. The relationship between the migration pattern of the sunn pest and temperature

Descriptive variables	B	Std. Error	Wald	df	Sig.	Exp(B)
Temperature (Mean)	,559	,084	43,846	1	,000	1,749
Temperature (Minimum)	-,175	,063	7,754	1	,005	,839
Temperature (Maximum)	,034	,033	1,015	1	,314	1,034
Constant	-5,543	,425	169,852	1	,000	,004
Number of observations	1204	Missing cases		11		
Log-Likelihood value	521,294					
Cox&Snell R^2	0,271					
Nagelkerke R^2	0,512					
Hosmer and Lemeshow Test	X^2=8,675; df=8; p=0,370					
Classification Table		Predicted				
Observed		$Phase_1$	$Phase_2$	Percentage correct		
$Phase_1$		1009	35	96.6%		
$Phase_2$		84	65	43.6%		
Overall Percentage		92.3%	65.0%	90.0%		

minimum temperatures affect the onset of movement for the pest in the wintering site and its migration pattern to the fields (Wald statistic sign. value). It can be observed that with an increase in temperature, both movement onset and migration accelerate (Exp(B)). However, upon examining the Classification Matrix, it was found that the prediction accuracy was low, particularly with a significant amount of error in predicting both the onset of movement and the migration pattern (56.40%). The Cox-Snell and Nagelkerke values also confirm our findings regarding the explanatory power of average and minimum temperatures on the migration pattern. This situation demonstrates that temperature may not be the main factor in initiating migration from the wintering sites. This indicates that the onset of migration from the wintering sites and the course of migration, which are the first critical points in forecasting-warning, cannot be determined solely based on temperature values.

When other studies are examined; it will be observed that temperatures at the wintering sites vary significantly (10-25 °C) depending on factors such as studies, years, countries, and regions within the same country when migration from the wintering sites begins. The dominant sunn pest species in the study area is *E. maura*. Although the findings were obtained from *E. maura*, they show considerable consistency with the results derived from other sunn pest species, as demonstrated in the studies presented below.

Silvestri (1934) found that sunn pests become active and migrate when the temperature rises above 10 °C during spring term in Italy. According to Arkhangel'skii (1939), migration from the wintering sites in the North Caucasus occurs when the temperature rises above 21 °C in the second half of April. On the other hand, Peredelskii et al. (1951) report that migration takes place when the average temperature in the first week of April is 16 °C. Similarly, Smolyannikov (1955) reports that overwintered adults migrate from wintering sites to grain fields when the temperature reaches 20-22 °C at the end of April in the same region.

In Iran's significant cereal production region of Varamine, studies on the migration of sunn pest (*E. integriceps*) from wintering sites to fields indicated that migration started when temperatures reached 20-22 °C according to Aleksandrov (1949), 18-20 °C according to Vojdani (1954), 20 °C according to Agacino (1972), and 13.5-14.3 °C according to Radjabi (2000). Tafaghodinia and Majdabadi (2006) reported that in their studies conducted in five different regions in Iran, the landing dates of *Eurygaster integriceps* from wintering sites to wheat fields and the temperatures on these dates varied from year to year. They mentioned that during the descents from the wintering sites, the long-term average temperatures were 12 °C in the Shazand, Arak, and Tafresh regions, and 14 °C in the Saveh region.

In studies conducted in Türkiye (specifically in Diyarbakır-Karacadağ wintering sites), sunn pests (*E. integriceps*) migrate from the wintering sites to the plains when the daily average air temperature in spring reaches 17 °C according to Lodos (1961), and when it exceeds 13 °C according to Karaca et al. (2009). In the same region, Kılıç (1978) reports that Sunn pests migrate from the wintering sites to the plains when temperatures in the wintering sites reach 18 °C in the second half of March to the beginning of April. Memişoğlu (1985) reported that the migration of sunn pests (*E. maura*) from wintering sites in Ankara province began in May with daily average temperatures of 14.8 °C, 15.1 °C, and 20.0 °C in the years 1981, 1982, and 1983, respectively.

Furthermore, in other studies conducted in Türkiye, according to İleri (1957), migration from the wintering sites occurs in the second half of March when temperatures reach 15-17 °C. Kılıç and Karslıoğlu (1961) state that migration occurs when the average temperature in the wintering sites ranges from 14-22 °C. Yüksel and Bayseç (1964) suggest a temperature threshold of 12 °C for migration, while Öncüer and Kıvan (1995) indicate that sunn pest (*E. integriceps*)'s migration occurs when temperatures in the wintering sites reach 14-16 °C.

According to studies conducted in Bulgaria, Grigorov and Gospodinov (1964) report that the temperature in the wintering sites reaches 17-18 °C in spring when adult sunn pests (*E. integriceps*) migrate from the wintering grounds to wheat fields. Similarly, Lazarov et al. (1969) state that migration occurs when temperatures reach 14-15 °C, while Nakova and Urukov (1976) indicate that migration begins when temperatures reach 18.6 °C.

In Romania, according to Barbulescu (1967, 1971), migration from wintering sites to wheat fields occurs when temperatures reach 12 °C. Similarly, Ionescu and Mustatea (1975) suggest that migration happens when temperatures are above 10 °C and, according to Paulian and Popov (1980), sunn pest (*E. integriceps*)'s migration occurs when temperatures reach 12-13 °C.

While there are numerous other studies similar to those mentioned above, it was deemed sufficient to omit them for the sake of discussion, given the literature provided. When the results obtained from our study are evaluated together with the studies conducted so far, it is observed that predictions based on daily temperature values may lead to erroneous conclusions.

Therefore, the applicability of forecast warning models based on the accumulation of temperatures above the developmental threshold (degree-days) for each life stage of insects, which are part of decision support systems aimed at assisting in determining survey and spraying times, has also been investigated in predicting the migration pattern of the sunn pest from wintering sites.

Total effective temperature

As a result of the studies, it has been determined that the effective temperature sums obtained for critical points in sunn pest control (onset and end of migration from wintering sites) show a high degree of variation (Table 4-5). The totals of effective temperatures for overwintered adults (two starting times (January 1, July) and threshold temperature (>0 °C, >10 °C) until they start and finish their descent vary according to years (min-max values) in the same location and locations in the same year. For instance, at the Kırşehir Hasanpaşa hill transmitting station wintering sites, calculations based on data collected from January 1st and using a threshold temperature above 10 °C indicate that the effective temperature sum for the start of descent of overwintered adults' averages 13.49 degree-days. However, it has been determined that this value varies significantly between years, ranging from 3.19 to 29.94 degree-days (Table 4). A similar situation is observed when considering a threshold temperature of 0 °C. The same situation was also observed as a result of studies conducted using data from the Ekecik mountain wintering site in Aksaray. It has been determined that the cumulative effective temperature sums until the completion of migration from the wintering sites also exhibit variation between years at the same location and between locations in the same year, similar to the variation seen at the start of descent (Table 4).

As the starting point for the day-degree calculation, the date of return of the new generation adults to the wintering sites for summer was taken as July. It has been determined that there was variation between years at the same location and between locations in the same year for both threshold temperatures, from the start to the completion of descent from the wintering sites (Table 5).

Table 5.

The analysis results for predicting Phase 2, which is the descent process of the sunn pest from the wintering sites, using cumulative effective temperature sums are provided in Tables 6-9. When examining the tables, it can be seen that while there was a high success rate in predicting the phases, the correct prediction rate of Phase 2 remained at a low level.

According to the analysis conducted for predicting the

Table 4. Total effective temperatures (degree-days) until the start of descent of overwintered adults from the wintering sites to the fields (1 January)

	Total effective temperatures (degree-days) until the start of descent of overwintered adults (January 1st)				**Total effective temperatures (degree-days) until the completion of descent of overwintered adults (January 1st)**			
Location	**Kırşehir- Hasanpaşa hill**		**Aksaray-Ekecik mountain**		**Kırşehir- Hasanpaşa hill**		**Aksaray-Ekecik mountain**	
Descriptive Statistics	**Threshold temperatures**		**Threshold temperatures**		**Threshold temperatures**		**Threshold temperatures**	
	>0 °C	**>10 °C**	**>0 °C**	**>10 °C**	**>0 °C**	**>10 °C**	**>0 °C**	**>10 °C**
Mean	342.64	13.49	290.47	6.67	492.84	38.27	419.19	24.86
Std. error	21.60	4.65	21.10	2.15	44.79	7.55	36.84	4.69
Minimum	273.07	3.19	218.54	1.43	394.06	20.76	320.27	13.22
Maximum	387.09	29.94	342.61	11.42	624.80	63.54	525.50	39.93
Std. deviation	48.29	10.39	47.18	4.82	100.15	16.89	82.38	10.48
Confidence interval 95%	282.68	0.58	231.89	0.69	368.49	17.30	317.62	11.85
	402.61	26.39	349.05	12.65	617.19	59.24	522.20	37.88

Table 5. Total effective temperatures (degree-days) until the completion of descent of overwintered adults from the wintering sites to the fields (July)

Location	Total effective temperatures (degree-days) until the start of descent of overwintered adults (July)				Total effective temperatures (degree-days) until the completion of descent of overwintered adults (July)			
	Kırşehir-Hasanpaşa hill		Aksaray-Ekecik mountain		Kırşehir-Hasanpaşa hill		Aksaray-Ekecik mountain	
Descriptive Statistics	Threshold temperatures		Threshold temperatures		Threshold temperatures		Threshold temperatures	
	>0 °C	>10 °C	>0 °C	>10 °C	>0 °C	>10 °C	>0 °C	>10 °C
Mean	2109.54	651.62	2027.48	613.91	2285.95	678.44	2190.85	636.68
Std. error	57.77	27.45	71.79	64.44	83.10	28.93	50.27	62.59
Minimum	1936.73	587.44	1813.69	422.60	2057.71	610.93	2052.81	453.20
Maximum	2175.26	715.83	2122.36	701.72	2415.11	752.07	2279.46	726.21
Std. deviation	115.54	54.90	143.58	128.89	166.20	57.87	100.54	125.18
Confidence interval 95%	1925.69	564.27	1799.02	408.82	2021.48	586.36	2030.87	437.49
	2293.38	738.97	2255.95	819.00	2550.42	770.52	2350.82	835.86

phases using cumulative temperatures above 0 °C from January 1st until the start of descent of overwintered adults, a success rate of 93.2% has been achieved, but the correct prediction rate for Phase 2 remains at 54.8% (Table 6). This indicates a high error rate of 45.2% in predicting the start and completion of the descent of overwintered adults from the wintering sites. When the developmental threshold was taken as 10 °C, the analysis results show that the correct prediction rate for Phase 2 remains similarly low at 49.6% (Table 7).

When the start of estivation (Phase 1) was taken as the starting point for degree-day calculations, it was determined that the success rates for predicting the start and end times of the sunn pest migration were very low for both threshold temperatures (Table 8-9).

As can be seen from the results obtained, meaningful conclusions cannot be drawn using effective temperature sums. It is clear that predictions made using these data will be insufficient to explain the course of the pest's migration.

When examining the studies conducted on the subject so far, it will be observed that there are significant differences in the developmental threshold values used in calculations related to effective temperature sums. Additionally, significant differences will be observed in the cumulative effective temperatures until the start and completion of descent of overwintered adults obtained as a result of calculations.

According to the study conducted by Ionescu and Mustatea (1975) in Romania over four years (1971-1973) at six different locations, they reported that the cumulative effective temperatures were between 13.8-19.4 degree-days when descent began and between 33.4-112.2 degree-days when descent ended (with a developmental threshold of 10 °C). The researchers stated that the cumulative effective temperature varies depending on the conditions during the descent. They indicate that under favorable conditions for sunn pest descent, the cumulative effective temperatures were low (33.40 degree-days) with average temperatures above 12 °C until May and low precipitation. However, under unfavorable conditions, such as average temperatures below 12 °C until May with precipitation, the cumulative effective temperatures were high (99.00 degree-days).

Popov and Barbulescu (1978) report that in the wintering sites of the Fundelea region of Romania (from 1965 to 1976), when the migration of sunn pests from the wintering sites to the grain fields began, the cumulative effective temperatures above 10 °C varied between 22.5 and 84.5 degree-days. They

Table 6. Total effective temperatures (degree-days) until the start of descent of overwintered adults from the wintering sites to the fields (1 January)

Descriptive variables	B	Std. Error	Wald	df	Sig.	Exp(B)
Total effective temperature >0 °C (gd)	-,015	,001	106,044	1	,000	,985
Number of observations	1580	Missing cases		0		
Likelihood Ratio Tests	X^2=2440,553; df=2; p=0,000					
Cox&Snell R^2	0,787					
Nagelkerke R^2	0,953					
Goodness-of-Fit (Deviance)	X^2=470,764; df=2564; p=1,00					
Classification Table			Predicted			
Observed	$Phase_1$	$Phase_2$	$Phase_3$		Percentage correct	
$Phase_1$	780	14	0		98.2%	
$Phase_2$	23	74	38		54.8%	
$Phase_3$	0	33	618		94.9%	
Overall Percentage	50.8%	7.7%	41.5%		93.2%	

Table 7. Total effective temperatures (degree-days) until the start of descent of overwintered adults from the wintering sites to the fields (1 January)

Descriptive variables	B	Std. Error	Wald	df	Sig.	Exp(B)
Total effective temperature >10 °C (gd)	-,084	,008	100,832	1	,000	,919
Number of observations	1580	Missing cases		0		
Likelihood Ratio Tests	X^2=2333,682; df=2; p=0,000					
Cox&Snell R^2	0,772					
Nagelkerke R^2	0,917					
Goodness-of-Fit (Deviance)	X^2=499,611; df=1318; p=1,00					
Classification Table			Predicted			
Observed	$Phase_1$	$Phase_2$	$Phase_3$		Percentage correct	
$Phase_1$	790	4	0		99.5%	
$Phase_2$	39	67	29		49.6%	
$Phase_3$	0	33	618		94.9%	
Overall Percentage	52.5%	6.6%	40.9%		93.2%	

also mention that the cumulative effective temperatures varied from year to year over the 12 years.

Radjabi (2000) reports that there is no correlation between the onset of sunn pest migration from the wintering sites to the grain fields and the effective temperature totals (degree-days).

Amir-Maafi et al. (2007) examined the relationship between cumulative effective temperature sums during the period from January 1st to the beginning of the first sunn pest descent to grain fields using 7 different threshold temperatures (0-2-4-6-8-10 and 12 °C) in Iran from 1992 to 2002. They found high variations from year to year and between locations, suggesting that cumulative effective temperature totals cannot be used to predict the initial migration of sunn pests from wintering sites.

Mozaffari and Azizian (2011) reported that the annual effective temperature sum varies according to the climatic conditions of the year, with the development threshold temperature taken as 6 °C ranging from 413.8 to 1132.7 degree-days. They indicate that along with the increase in the annual effective temperature sum, there will also be increases in the population density of sunn pests.

Table 8. Total effective temperatures (degree-days) until the start of descent of overwintered adults from the wintering sites to the fields (July)

Descriptive variables	B	Std. Error	Wald	df	Sig.	Exp(B)
Total effective temperature >0 °C (gd)	-,011	,001	295,667	1	,000	,989
Number of observations	2925	Missing cases		0		
Likelihood Ratio Tests	X^2=3356,69; df=2; p=0,000					
Cox&Snell R^2	0,682					
Nagelkerke R^2	0,903					
Goodness-of-Fit (Deviance)	X^2=757,70; df=4812; p=1,00					
Classification Table				Predicted		
Observed	$Phase_1$	$Phase_2$	$Phase_3$		Percentage correct	
$Phase_1$	2125	15	0		99.3%	
$Phase_2$	45	41	49		30.4%	
$Phase_3$	13	19	619		95.1%	
Overall Percentage	74.6%	2.6%	22.8%		95.2%	

Table 9. Total effective temperatures (degree-days) until the start of descent of overwintered adults from the wintering sites to the fields (July)

Descriptive variables	B	Std. Error	Wald	df	Sig.	Exp(B)
Total effective temperature >10 °C (gd)	-,018	,001	190,633	1	,000	,982
Number of observations	2925	Missing cases		0		
Likelihood Ratio Tests	X^2=1497,21; df=2; p=0,000					
Cox&Snell R^2	0,401					
Nagelkerke R^2	0,530					
Goodness-of-Fit (Deviance)	X^2=757,70; df=4812; p=1,00					
Classification Table				Predicted		
Observed	$Phase_1$	$Phase_2$	$Phase_3$		Percentage correct	
$Phase_1$	2140	0	0		100.0%	
$Phase_2$	122	0	13		0.0%	
$Phase_3$	192	0	459		70.5%	
Overall Percentage	83.9%	0.0%	16.1%		88.8%	

Decision tree models

A third method was used to predict the first of the field-based surveys, which is the first of the primary survey times for control purposes. This method relies on the starting times of the biological events of the sunn pest, explaining the relationship between temperature values and the beginnings of these biological events by using machine-learning techniques. The results obtained from this method are presented in Table 10. The predictions made using only temperature data obtained from meteorological stations in the wintering sites resulted in an accuracy rate of over 90% (ranging from 82.94% to 96.44%). However, as can be seen upon examining in the error matrix, more than 100 (ranging from 104 to 499) incorrect predictions were made. Especially, the accuracy rate in predicting the duration of Phase 2, where the valuation survey is determined, remains very low (ranging from 0.00 to 38.00).

Conclusions

Studies investigating the applicability of forecast warning models created solely with temperature data in the context of sunn pest control have shown that temperature values alone (minimum, average, maximum) cannot explain the migration pattern of the pest from overwintering sites, which is a critical aspect in pest management.

Table 10. Prediction results for the onset of assessment surveys using one of temperature data

Measured data		The accurate prediction rate (%)	Number of prediction: Incorrect	Number of prediction: Correct	Total	Error Matrix: Phases	P_1	P_2	P_3	The accurate prediction rate (%)	Location	Number of loops
Air temperature	Max.	96.44	104	2821	2925	Phases	P_1	P_2	P_3		2	4
						P_1	2129	10	0	99.53		
						P_2	48	48	32	38.00		
						P_3	6	6	644	97.87		
	Avg.	93.95	177	2748	2925	Phases	P_1	P_2	P_3		2	4
						P_1	2123	0	16	99.25		
						P_2	77	1	50	0.78		
						P_3	28	6	624	94.83		
	Min.	82.94	499	2426	2925	Phases	P_1	P_2	P_3		2	4
						P_1	2138	0	1	99.95		
						P_2	128	0	0	0		
						P_3	370	0	288	43.77		

Error type	Measured data: Minimum	Measured data: Average	Measured data: Maximum
Mean Absolute Error	0,0047	0,0058	0,0045
Root Mean Square Error	0,0642	0,0733	0,0653
Relative Absolute Error	1,7086%	2,0946%	1,5959%
Root Relative Squared Error	17,2271%	19,6748%	17,4761%

It is evident that insect bioecology, which involves multiple relationships, cannot be explained by a single factor. We believe that forecast warning models created using artificial intelligence techniques and utilizing all meteorological data will explain migration patterns, which are influenced by multiple meteorological factors, with higher accuracy rates.

Based on our research specifically focused on the sunn pest, we conclude that forecast warning models created for pest control, incorporating all meteorological data and utilizing commonly used artificial intelligence techniques, will yield higher accuracy in predictions.

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Author's Contributions

Authors declare the contribution of the authors is equal.

Statement of Conflict of Interest

The author declared no conflict of interest.

ÖZET

İnsan beslenmesinin vazgeçilmez ürünlerinin başında gelen buğdayın, verim ve kalitesini olumsuz yönde etkileyen önemli zararlıların başında Süne (Eurygaster spp.) gelmektedir. Süne ile mücadelede, zararlının kışlaklardan buğday alanlarına göç seyrinin belirlenmesi kritik öneme sahiptir. Bu göç olayının başlangıç ve son bulmasının tahmin edilebilmesi süne mücadelesi tahmin uyarı çalışmalarının temelini oluşturmaktadır. Sünenin kışlaktan ovaya inişinin başlama ve bitişini sıcaklık verileri ile tahmin edilebilirliğinin araştırıldığı bu çalışma; 2014-2018 yıllarında 2 kışlakta 4 yaşam döngüsü süresince yürütülmüştür. Elde edilen veriler 3 yöntem; herhangi bir işlem yapılmadan salt sıcaklık değerleriyle, etkili sıcaklık toplamlarının kullanıldığı gün derece modeli ve birikimli sıcaklık değerlerinin kullanıldığı makine öğrenmesi (karar ağacı) yöntemleri ile değerlendirilmiştir. Yapılan çalışmalar sonucunda; sünenin ovaya göç seyrinin sadece sıcaklık verileri ile açıklanamayacağı belirlenmiştir.

Anahtar kelimeler: süne, buğday, tahmin-uyarı

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