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Remote sensing wi monitoring wheat grain beetle, *Anisoplia sp*. to evaluate the severity of wheat infestation in Erbil Province

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Geographic information system, *Anisoplia* pest, Soil analysis, Severity of wheat infestation, Pest management.

ABSTRACT

This study was undertaken to monitor and assess the distribution of the wheat chafer, *Anisoplia* sp. and to determine how severe wheat crop could be infested by the beetle, utilizing both traditional field surveys and Geographic Information Systems (GIS) technology. The beetle is a destructive soil pest that causes severe damage to various cereal crops. Thus, the study analyzed key soil parameters including (soil texture, EC, pH, organic matter) and crop biological parameters including (chlorophyll content, water content, and Leaf Area Index) to assess the health of wheat crops and the impact of beetle infestation. The larval stage was collected from wheat fields across twelve villages located in the four directions of Erbil (North, East, West and South) in various period of time (November, January, and March), and GIS data was used to map the spatial distribution of infestations. Results indicated significant variation in the beetle population density and severity of wheat infestation across different geographic locations, with the highest levels of 7.51 larvae /M^2 and 54.39% wheat infestation observed in villages located in the West direction of Erbil. Further, January 2023 attained the highest larvae population, 7.32 larvae /M^2. The population density of the larvae correlated with both the texture and organic matter of the soil. GIS-based mapping revealed correlations between field-collected data and remote sensing parameters, enabling accurate prediction of infestation severity. The study demonstrates the potential of integrating traditional and modern techniques to monitor pest populations and improve pest management strategies in wheat production.

1.Introduction

Wheat, *Triticum aestivum* L., is an economic staple food crop with adaptability to a broad range of climates and geographical locations, occupying almost 18% of all arable land (Dixon et al., 2009). The desire for greater wheat output is as strong as ever, owing to the rapid development of the human population, which has resulted in an increase in average annual global wheat production worldwide (Grote et al., 2021). Iraq is one of the countries that has been interested in cultivating the wheat crop since early times and increasing the area cultivated to meet the basic needs of its citizens. Consequently, the area cultivated with wheat in Iraq has increased year by year to meet the demand of the local market (Abbas et al., 2024).

The fact that farmers are still facing significant challenges due to inadequate rate of wheat output per hectare compared to international rates, despite the enormous area of Iraq covered with the wheat crop might refer to the deficiency of employing modern methods and technologies (Abdulrahman et al., 2023, Khidr and Khalil, 2024). Geographical information system (GIS) data is a novel technology that is becoming more widely available for the purpose of land management and conservation, thus the evaluation of large-scale ecosystem change is significantly influenced by the predictions of plant and animal species (Kingra et al., 2016, Dong et al., 2019, Al-Quraishi and Negm, 2020, Khwarahm, 2023). Consequently, geospatial technology has undoubtedly played a significant role in the development of new strategies for the management of insect pests and diseases in agricultural crops, thereby enhancing productivity and production via monitoring the spatial dynamics and impact on vegetation (Anwer and Singh, 2019).

The Anisopliinae beetles, *Anisoplia* sp. (Coleoptera: Scarabaeidae: Rutelinae) is a polyphagous pest that inflicts significant damage on a variety of cereal crops (i.e. wheat, barley, maize, and oat (Jameson et al., 2007, Özgökçe et al., 2024). The Anisopliinae beetles and occasionally known as grain beetles, is a major pest affecting wheat in Iraq and several neighboring countries including Iran, Syria and Turkey which leads to considerable economic losses due to its adult and larvae as feed on the roots and the grains of wheat plants (Micó et al., 2009, Ramadhan, 2011, Karimi et al., 2015, Özgökçe et al., 2024). *Anisoplia* species are invasive soil pests that have a major negative impact on grain harvests and result in economic losses. They also lower wheat yields, impair plant vigor, and increase susceptibility to diseases in both adult and larval stages (Miller and Pike, 2002, Malhamchi, 2010, Isawi et al., 2023). Deploying GIS technique in wheat fields to monitor the pest infestation levels and the distribution rate across varied geographic areas and periods of time will certainly boost crop yields (Ghosh and Kumpatla, 2022).

A manual survey employing various traditional traps is the most common practice for monitoring insect pests in the field. However, conventional methods of insect pest monitoring can be quite time-consuming and lack precision when applied to larger areas, especially on cereal crops (Ranjan and Vinayak, 2020, Faqe Ibrahim et al., 2023). Implementing insect monitoring using GIS systems has the potential to create new opportunities and possibilities from understanding the past and present state of the insect pest population, movement, and infestation problem in diverse fields with different climatic conditions which is important for facilitating the development of integrated pest management policies to achieve sustainable agriculture management.

Forecasting the distribution of ground beetles is not only important for predicting the possible infestation by these destructive insect pests, but also for assessing the potential damage to wheat crop to apply the control methods accordingly. However, a scarcity of research is available on the use of GIS data to monitor the insect pest distribution in cereal fields in Iraq. Therefore, this study was conducted to monitor the impact of *Anisoplia* sp. on wheat crops via both traditional (field survey) and innovative approaches (GIS) which led to improved wheat productivity by accurately forecasting beetle infestations in the large area under cultivation and enabling the timely application of control methods via employing this new technique that could influence future pest management research and policy.

2.Material and methods

2.1 Sample collection for species identification

The *Anisoplia* sp. were collected from soil in Erbil province either manually pickings or via using pitfalls traps (diameter 21 cm, height 17 cm) inside wheat fields. The specimen was identified via using taxonomic keys (Mico et al., 2001, Galante and Micó, 2005, Jameson et al., 2007) and further confirmed by an expert taxonomist in the Department of Plant Protection-College of Agricultural Engineering Sciences- Salahaddin University and an expert in the Ministry of Agriculture and Water Resources.

2.2 GIS assay

The spatial distribution of *Anisoplia* sp. using GIS was evaluated during field visits to collect geographical coordinates (X=Longitude, Y=Latitude) from twelve wheat fields in four directions within the Erbil Province as seen in (Table 1). A total of 108 points were allocated, with 9 points selected from each field via using Bosch GLM 50-23 GPS with at least ten meters away from the edge of the field (appendix Table 1-4). A five-month timeframe, commencing in November 2022 and concluding in March 2023, was allocated for collecting and processing data obtained from the satellite images to evaluate wheat biological parameters for chlorophyll a and b (Cab), canopy water content (CWC), and leaf area index (LAI).

Table 1: Coordinators (X=Longitude, Y=Latitude) of wheat fields where larvae, soil and plant samples were collected in various geographical locations of Erbil Province

Village names	X(longitude)	Y(latitude)	Direction
Drash	44.0751	36.3804	North
Segrka	44.0883	36.3732	North
Bapirtan	44.0353	36.3672	North
Punjina	44.1850	36.1360	East
Grdeshisaru	44.2317	36.1356	East
Brka	44.2373	36.1961	East
Qushtapa	44.0354	36.0039	South
Murtkagchka	44.0347	36.0358	South
Dukala	43.9674	36.9331	South
Ashokan	43.9330	36.3143	West
Daraban	43.9054	36.3032	West
Barhoshtr	43.8890	36.3456	West

2.3 Field assay

Sample collection of the larvae from soil in the twelve wheat fields in the above-mentioned section, started in the same period (November 2022 till March 2023), ensuring that they are in alignment with the locations examined in the GIS-based assay. Larvae samples were collected from 1 M^2 in the same points of GIS (Mansfield et al., 2016). Then samples were placed inside polyethylene bags that contained labels written on village names, directions, and dates. Samples were carried back to the laboratory for further examination under a binocular dissecting microscope.

Further, the severity of wheat infection was calculated by randomly selecting 20 plants from 1 M^2 area and the infection index was calculated as below formula:

%Severity of infection = (a*1) + (b*2) + (c*3) (d* 4)+(e*5)/ (a+b+c+d+e)* 5(McKinney, 1923) where a, b, c, d, and e are the number of plants with levels of infestation of 0, 1, 2, 3,4, and 5 respectively and 5 is the highest score of infestation.

2.4 Laboratory assay

2.4.1 (Measurement of wheat biological parameters)

2.4.1.1 Chlorophyll content estimation of wheat crop

A total sample size of 3240 leaves from 1080 wheat plants has been used in the test as three leaves from each plant were examined from the surveyed wheat fields. Samples were inspected using a SPAD-502 chlorophyll meter (Minolta, Japan) which has been extensively employed for the investigation of a variety of plant species (Islam et al., 2014).

2.4.1.2 Water content measurement of wheat crop

A total of 1080 samples of wheat were inspected by weighing five grams of fresh leaves from each plant using a sensitive electronic balance to an accuracy of 0.001 mg (Techfit, China). Subsequently, the weighed samples were oven-dried at 80°C for 72 hours, and water content was determined by utilizing the following equation as described by (Jin et al., 2017).

WC = FW-DW/FW*100

Where: WC=Water content, FW= Fresh weight and DW= Dry weight

2.4.2 (Measurement of soil biological parameters)

2.4.2.1 Sample collection

Soil samples were collected from taken from the twelve aforementioned villages of Erbil Province in section 2.2 (Table1) in a surface layer between 0 – 0.3m then the samples were air-dried and ground to pass through a 2mm sieve for subsequent analysis.

2.4.2.2 Soil pH

The soil pH of the saturated extract was measured with a pH-meter; model 332 JANEWAY followed methods by (Motsara and Roy, 2008)

2.4.2.3 Electrical conductivity (EC)

The EC was measured using EC-meter Model CM-205, and adjusted to 25C° (Rowell, 2014).

2.4.2.4 Organic matter content (OM)

The OM was determined by Walkley and Black method (Krishnan et al., 1980).

2.4.2.5 Particle size distribution

The hydrometer method was used to measure the particle size distribution according to the method by (Hunduma and Kebede, 2020). The Soil Texture Triangle was used to determine the soil texture based on the percentage of sand, silt, and clay

2.5 Statistical analysis

Population density and severity of infestation with all biological parameters in the laboratory, field, and GIS assay were measured using the General Linear Model using Factorial analysis of variance (ANOVA) in a statistical package of social science (SPSS) version 23 followed by Fischer's least significant difference (LSD) test to determine statistical differences between means at $P \leq 0.05$. The spectral vegetation indices were estimated in Snap Sentinel-2 software program version 9.0 as the optical features were utilized by selecting thematic land processing for the measurement of Cab chlorophyll, canopy water content, and leaf area index. The processed images were transferred to ArcGIS software program version 3.1 used to create Arc maps to assess the population density of *Anisoplia* spp via (X, Y) coordinates and reflectance variation as each parameter was depicted individually with distinct colors across different parts of the studied area via using satellite images that were obtained from Esa Copernicus Open Access Hub website (https://www.copernicus.eu/en/about-copernicus).

A Pearson correlation analysis was conducted using IBM SPSS Statistics software, version 23, to assess the relationship between field data (Chlorophyll, Water content, Severity of infestation) and GIS data (Cab, CWC and LAI) and establish the correlation between them in sequences. Also to evaluate the relationship between population density of the larvae and soil properties (Soil texture, EC, pH and OM). The Pearson correlation coefficient (*r*) was used to determine the strength and direction of the linear association between the two variables and the statistical significance was set at $P \leq 0.05$.

3.Results

3.1 Field assay

3.1.1 Population density of *Anisoplia* sp. larvae

The population number of *Anisoplia* sp. larvae exhibited variation across three key factors: surveyed villages, direction, and the period of study. Hence, the experiment revealed that the larvae were significantly varied in different villages ($F_{(11,215)} = 20.24$, $P < 0.001$), Hence, the highest population was recorded in Barhoshtr village which was 8.30 larvae/M^2 that didn't differ significantly from Daraban 7.34 larvae /M^2, while the lowest number was recorded in Bapirtan, Segrka and Drash (1.14,1.26 and 1.54 larvae/M^2) respectively, with no significant differences between them (Figure 1a). The direction where the village was positioned had a significant influence on the beetle population ($F_{(3,215)} = 56.28$, $P < 0.001$). Consequently, the West route of

Erbil exhibited the highest population of larvae, with an average of 7.51 larvae/M^2. Conversely, the villages located in the North direction of Erbil had the lowest population, with 1.31 larvae/M^2 (Figure 1b). On the other hand, the abundance of the larvae was fluctuated in different months ($F_{(2,215)} = 98.34$ $P < 0.001$). Henceforth, the number of grain beetle larvae was at the lowest level in November and reached a peak in January (Figure 1c).

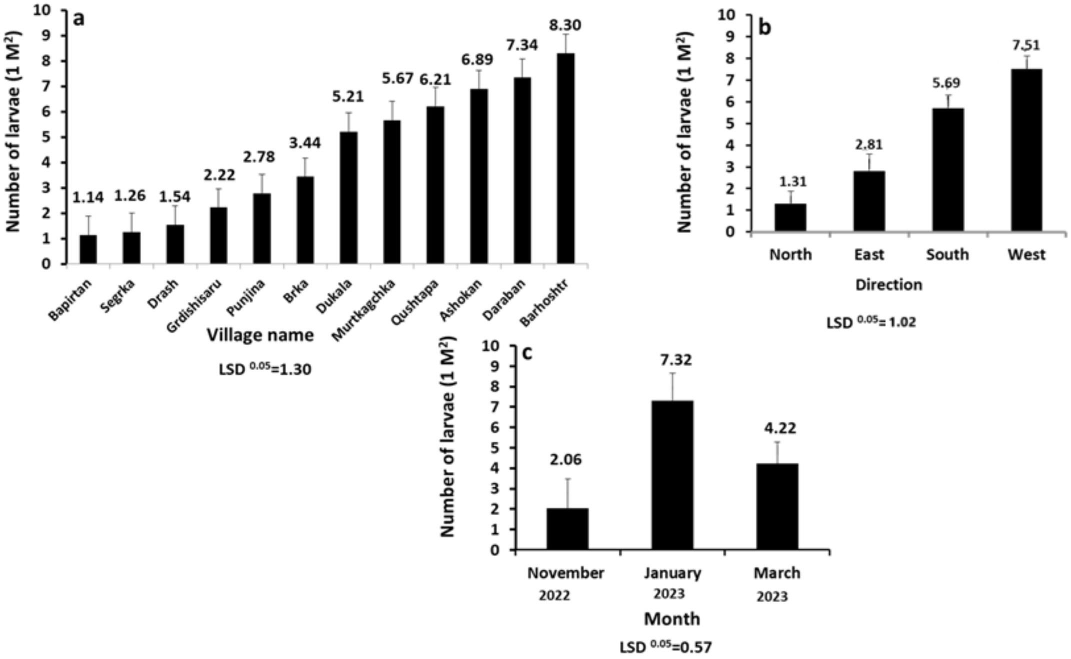

Figure 1: Population density of *Anisoplia* larvae on wheat crop in association: with, (a) surveyed villages, (b) directions of Erbil and (c) period of study

3.1.2 Severity of wheat crop infected by *Anisoplia* sp.

The severity of wheat infection exhibited variation by the villages ($F_{(11,215)} = 19.58$, $P < 0.001$). Wheat infection reached its peak severity at 58.90% in Barhoshtr village, while the lowest infestation was recorded in Bapirtab village 16.76% (Figure 2a). Additionally, the direction of the study area affected significantly what plant infestation by the larvae ($F_{(3,215)} = 43.56$, $P < 0.001$). Thus, the maximum value recorded in the West direction was 54.39%, while the North side of Erbil experienced the least severe form of wheat infestation and was 19.36% (Figure 2b). Moreover, the intensity of wheat infection was adjusted based on the time frame of the surveyed month ($F_{(2,215)} = 22.78$, $P < 0.001$). In November 2022, a severity level of 23.89% was documented, which then rose to 42.34% in March 2023 (Figure 2c).

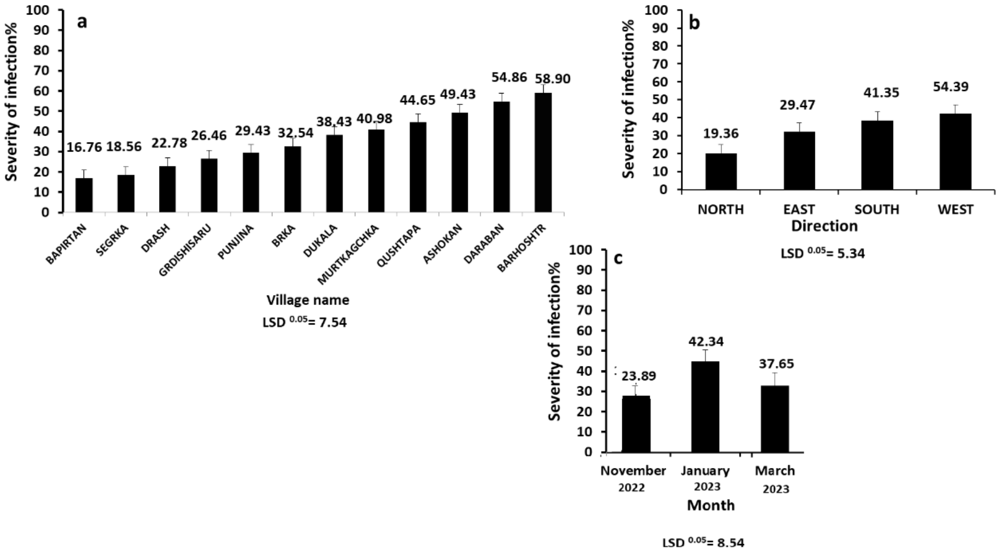

Figure 2: Percentage severity of wheat crop infestation by *Anisoplia* sp. in association with, (a) surveyed villages, (b) directions of Erbil and (c) period of the study

3.1.3 Chlorophyll content estimation of wheat crop

Based on the chlorophyll levels in plants affected by the beetle, the results showed significant variation across different villages ($F_{(11,215)}$=5.23, P <0.001). The highest chlorophyll content was found in Bapirtan, with 54.32 SPAD/leaf, followed by Segrks at 48.76 SPAD/leaf. In contrast, Barhoshtr had the lowest chlorophyll level, which was not significantly different from the levels in Daraban and Ashokan (22.42, 25.21, and 26.43 SPAD/leaf, respectively) (Figure 3a). Chlorophyll levels also varied significantly based on the direction of the survey zone ($F_{(3,215)}$=9.58, P <0.001). The Northern region of Erbil had the highest chlorophyll level at 49.54 SPAD/leaf, whereas the Western region had the lowest at 22.27 SPAD/leaf (Figure 3b). Additionally, the intensity of chlorophyll was significantly affected by the timing of the survey, which aligned with the beetle's appearance ($F_{(2,215)}$=5.33, P <0.001) (Figure 3c).

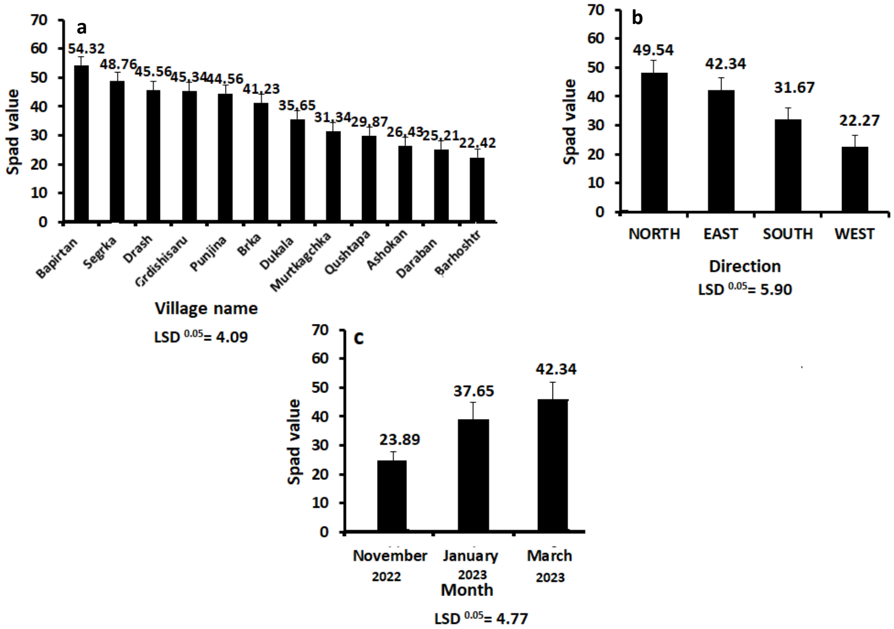

Figure 3: SPAD chlorophyll of wheat crop in association with, (a) surveyed villages, (b) directions of Erbil, and (c) period of the study

3.2 Laboratory assay

3.2.1 Water content measurement of wheat crop

The study revealed significant differences in the water content per leaf of the plants affected by the wheat grain beetle ($F_{(11,215)}$=495, P <0.001). Data showed that Bapirtan and Segrka had the highest leaf water content, at 0.008%, while Barhoshtr, Daraban, and Ashokan had the lowest at 0.001% (Figure 4a). Additionally, water content varied notably based on the geographic orientation of the wheat fields ($F_{(3,215)}$=765.52, P <0.001). The northern direction had the highest water content at 0.008%, significantly differing from other directions, while the western direction had the lowest at 0.003% (Figure 4b). Water content in the foliage was also affected by the timing of *Anisoplia* sp. infestation, with the highest content recorded in November at the start of the infestation (0.005%), and the lowest in January during peak infestation (0.003%), with a decrease to 0.0045 at the end of the infestation ($F_{(2,215)}$=56, P <0.001). (Figure 4c).

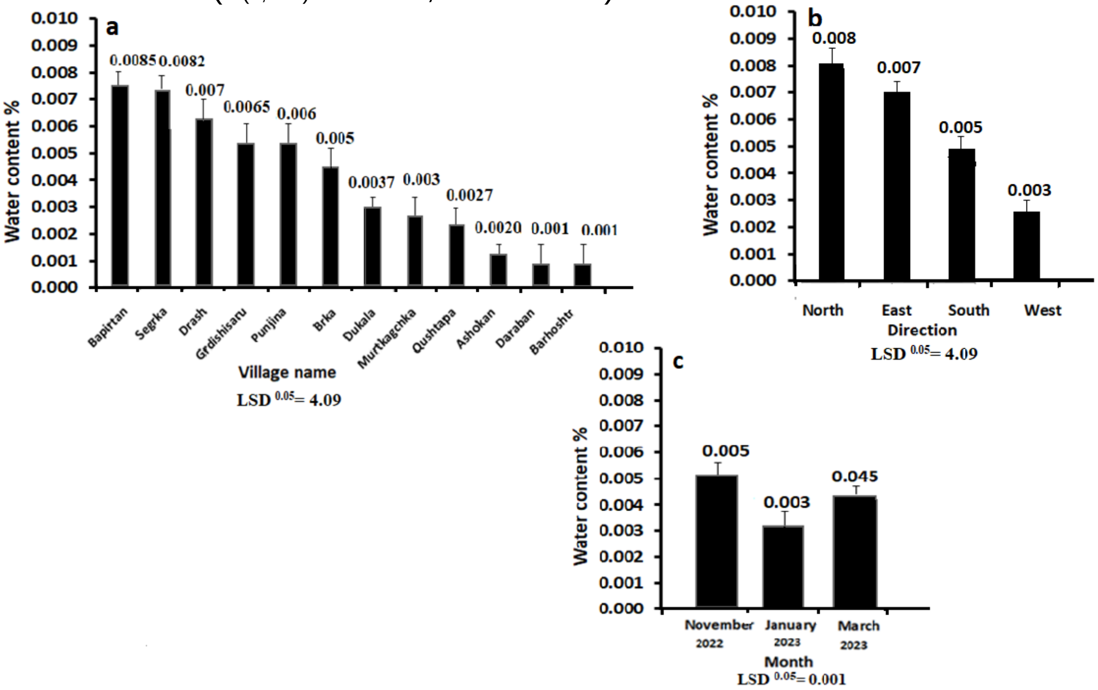

Figure 4: Percentage water content of wheat crop in association with, (a) surveyed villages, (b) directions of Erbil and (c) period of the study

3.3 GIS assay

3.3.1 Estimating Cab chlorophyll of wheat crop

The amount of chlorophyll found in the plant varied in accordance with villages that were affected by the. beetle ($F_{(11,215)}$= 21.56, P <0.001), throughout the period of the study. The highest Cab µg/CM^2 value recorded in Bapirtan village that was 60.32 µg/CM^2 followed by Drash and Segrka were 53.89 µg/CM^2 and 48.89µg/CM^2 respectively while the lowest was observed in Ashokan village that was 22.45 µg/CM^2 (Figure 5a).Cab chlorophyll rate was also changed in a different direction of Erbil Province ($F_{(3,215)}$= 39.22, P <0.001), the maximum value was recorded in North site of Erbil that was 59.89 µg/CM^2 while the lowest amount of chlorophyll was observed in West direction that was 8.78 µg/CM^2 (Figure 5b)..Furthermore, the time after infection with *Anisoplia* sp. beetle significantly affected the amount of chlorophyll matter ($F_{(2,215)}$=112.27, P <0.001) this was observed at the beginning of infestation in November 2022 the amount of Cab chlorophyll was 45.09 µg/CM^2 while in January 2023 was 17.54 µg/CM^2 and at the end of infestation with the beetle, the amount of Cab chlorophyll in March was increased to 31.67 µg/CM^2 (Figure 5c).

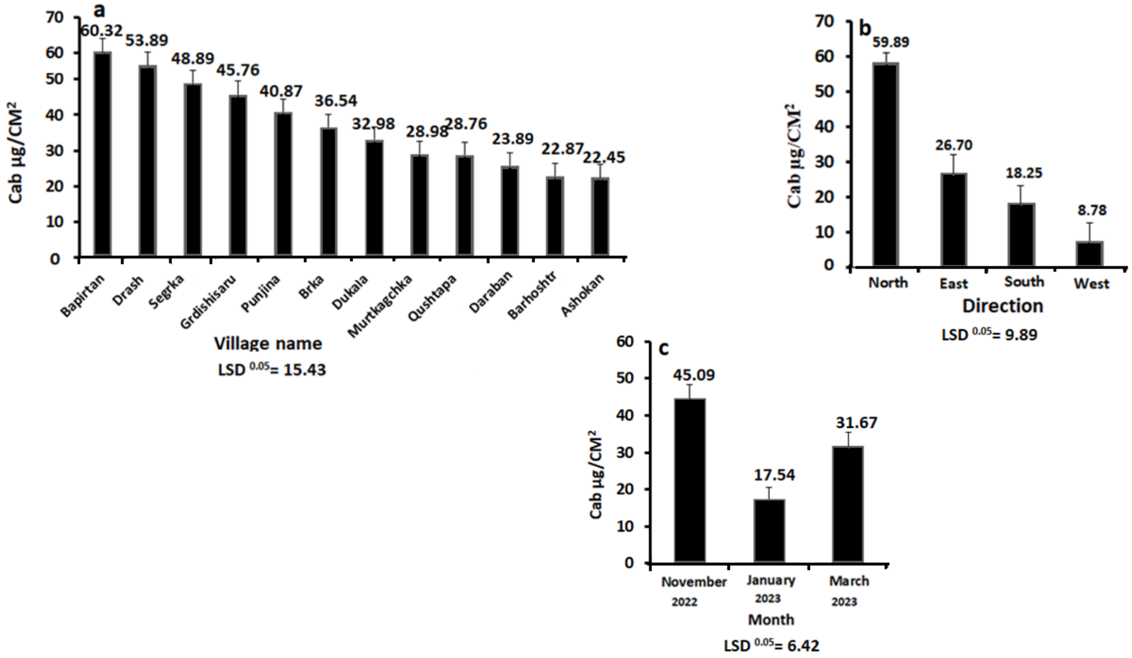

Figure 5: Cab chlorophyll of wheat crop in sampled areas in association with, (a) surveyed villages (b) directions of Erbil and (c) period of the study

3.3.2 Canopy water content estimation of wheat crop

Canopy water content (CWC) was also significantly varied in different villages ($F_{(11,215)}$= 29.23, P <0.001) thus, the highest CWC was found in Bapirtan 0.025 g/CM^{-2} followed by Segrka that was 0.022 g/CM^{-2}while the lowest value was recorded in Barhoshtr village that was 0.001 g/CM^{-2} followed by Daraban and Ashokan were 0.001 and 0.003 g/CM^{-2} respectively (Figure 6a)..Furthermore, the geographic location of villages had a significant impact on the water content ($F_{(3,215)}$ =82.11, P<0.001) hence, the maximum water content of wheat crop was observed in the North direction which was 0.020 g/CM^{-2} while, the lowest value was 0.003 that recorded in the West direction (Figure 6b). In addition, the time after insect infestation had a substantial impact on the plant's water content ($F_{(2,215)}$ =99.31, P<0.001), as a result, the maximum amount of water was measured in November 2022 and it was 0.03 g/CM^{-2} while the lowest value was observed in January 2023 and it was 0.01 g/CM^{-2} and it was increased with the reduction of infestation which recorded in March that was 0.02 (Figure 6c).

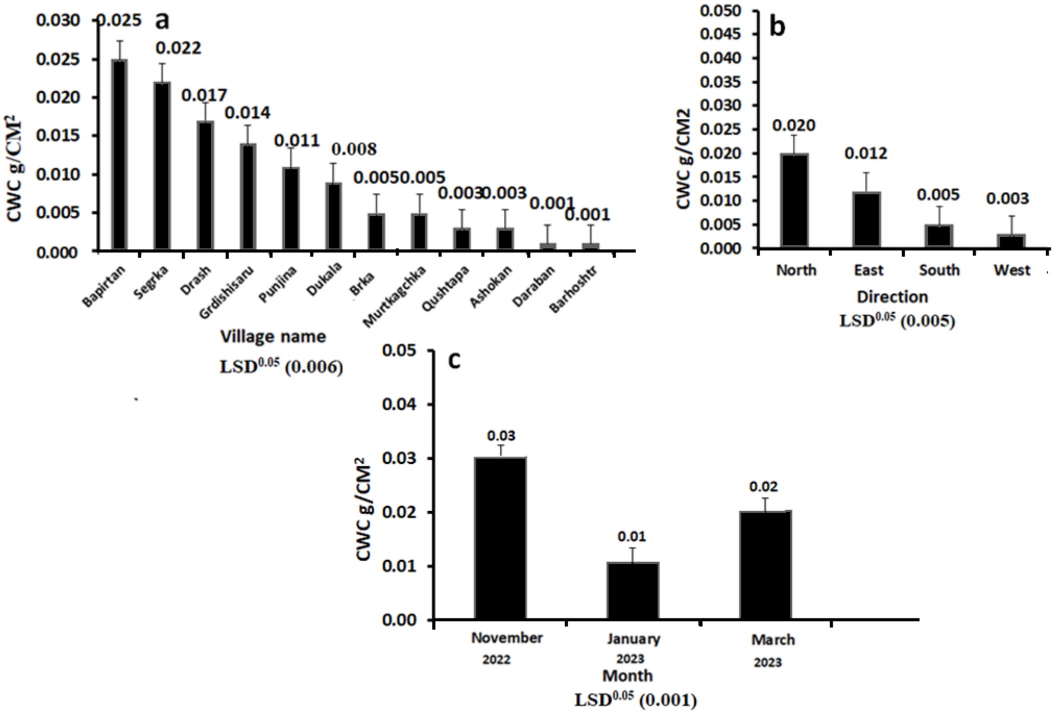

Figure 6: CWC of wheat crop in sampled areas in association with, (a) surveyed villages, (b) directions of Erbil and (c) period of the study

3.3.3 Leaf area index estimating of wheat crop

The Leaf Area Index **(**LAI) in GIS results indicated that there was significant variation in the amount of leaf canopy content in different villages $F_{(11,215)}$=18.11, P <0.001) thus, the highest LAI was recorded in Bapirtan village that was 2.00/LAI followed by Segrka and Drash which were (1.57/LAI and 0.93/LAI) respectively while the lowest LAI was recorded in Barhoshtr village that was 0.09 followed by Daraban and Ashokan which were (0.11/LAI) for each of them (Figure 7a). Additionally, different directions recorded different amounts of LAI ($F_{(3,215)}$= 45.23, P <0.001), the maximum value of LAI recorded in the North that was 1.25/LAI however the lowest value was recorded in the West direction that was 0.14/LAI (Figure 7b). Furthermore, the time period after infection significantly affected the LAI ($F_{(2,215)}$= 78.44, P <0.001) the highest amount of LAI was recorded in November 2022 which was 0.65/LAI while during the peak of infection by the best was in January was 0.20/LAI and in the end of infection in March 2023 the amount of LAI increased which was 0.40 (Figure 7c).

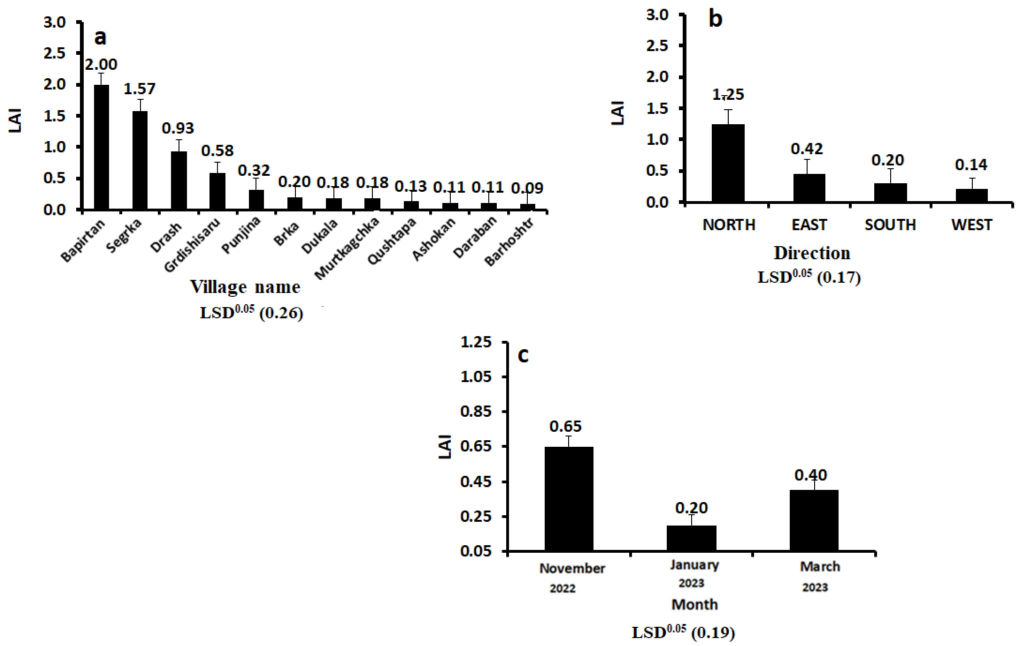

Figure 7: LAI of wheat crop in sampled areas in association with, (a) surveyed villages, (b) directions of Erbil and (c) period of the study

3.4 Designing Arc maps

3.4.1 Arc map for the spatial distribution of *Anisoplia* sp.

The distribution of the grain beetle was different in accordance with the location of villages and their directions, by taking GPS points (longitude and latitudes) coordinates from the surveyed area (Figure 8).

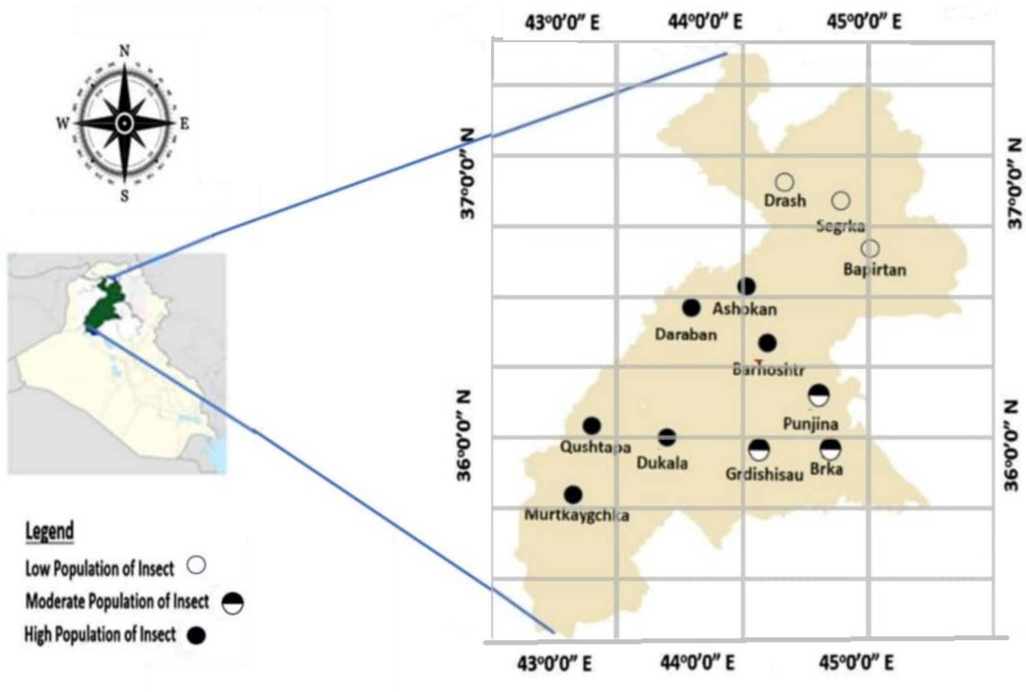

Figure 8: Map of Erbil Province of Iraq illustrating the spatial distribution of *Anisoplia* sp. using ArcGIS software program by adding X, and Y coordinates in surveyed areas

3.4.2 Reflectance variation of Cab chlorophyll, CWC and LAI of wheat fields Infested with the beetle

In November 2022 and January 2023, spectral reflectance data showed that foliar Cab chlorophyll, canopy water content (CWC), and leaf area index (LAI) of wheat were lower in infested fields compared to less damaged ones, as analyzed using ArcGIS and Sentinel-2 software (Figure 9). This indicates that late-stage infestation not only reduces the biochemical content of the foliage but also affects the accuracy of its retrieval. Early-stage infections had higher levels of Cab chlorophyll, resulting in dark green pixels that indicated healthy wheat coverage. Light green pixels represented slightly infected areas, yellow pixels indicated moderate infection, and red pixels signified heavily infested regions. Additionally, CWC is a crucial factor for assessing leaf traits and infestation levels of *Anisoplia* sp. the indigo color reflects normal water content, while azure blue indicates fewer infected plants.

However, the light blue tuft indicates a moderately infected plant by the wheat beetle, while the sky-blue color shows a highly stressed wheat plant in the observed fields. Additionally, the leaf canopy content (LAI) reflects the severity of stress, with dark purple signifying a healthy wheat crop with a high canopy content. Light purple indicates a slightly infected area, red denotes moderate beetle infestation, and yellow represents the highest level of infection by *Anisoplia* sp. (Figure 9a) Arc map to exhibit a different level of spectral reflectance of, Cab, CWC and LAI rate in infested fields with the beetle in November 2022 in Erbil Province. Temporal analysis showed that there were subtle changes observed among sampled fields and the direction of villages thus the maximum infestation level was recorded in (Ashokan, Barhoshtr and Daraban) located in the West direction with (Qushtapa, Murtkagchka and Dukala) that situated in South direction of Erbil Province, moderate infection was recorded in the Eastern regions of Erbil (Brka, Punjina, and Grdeshisaru), while lower infestation levels by the beetle were found in the Northern villages (Bapirtan, Drash, and Segrka). This pattern was observed between November 2022 and January 2023. However, the two periods showed significant differences in the estimation of all biological parameters obtained from remote sensing data. In January 2023, there was a notable decrease in Cab, CWC, and LAI, indicating the peak of infection across all villages, compared to the data collected in November 2022. The results also showed that remote sensing techniques are effective in the early detection of infestations by the wheat grain beetle. The study demonstrated that during the green attack stage, the beetle infestation alters the leaf spectral response and its biochemical properties, which can be detected using hyperspectral measurements. Additionally, the findings indicated significant differences in all measured leaf traits between healthy and infested samples, with higher Cab and LAI values helping to detect subtle changes in chlorophyll and canopy caused by the *Anisoplia* infestation throughout the study period.

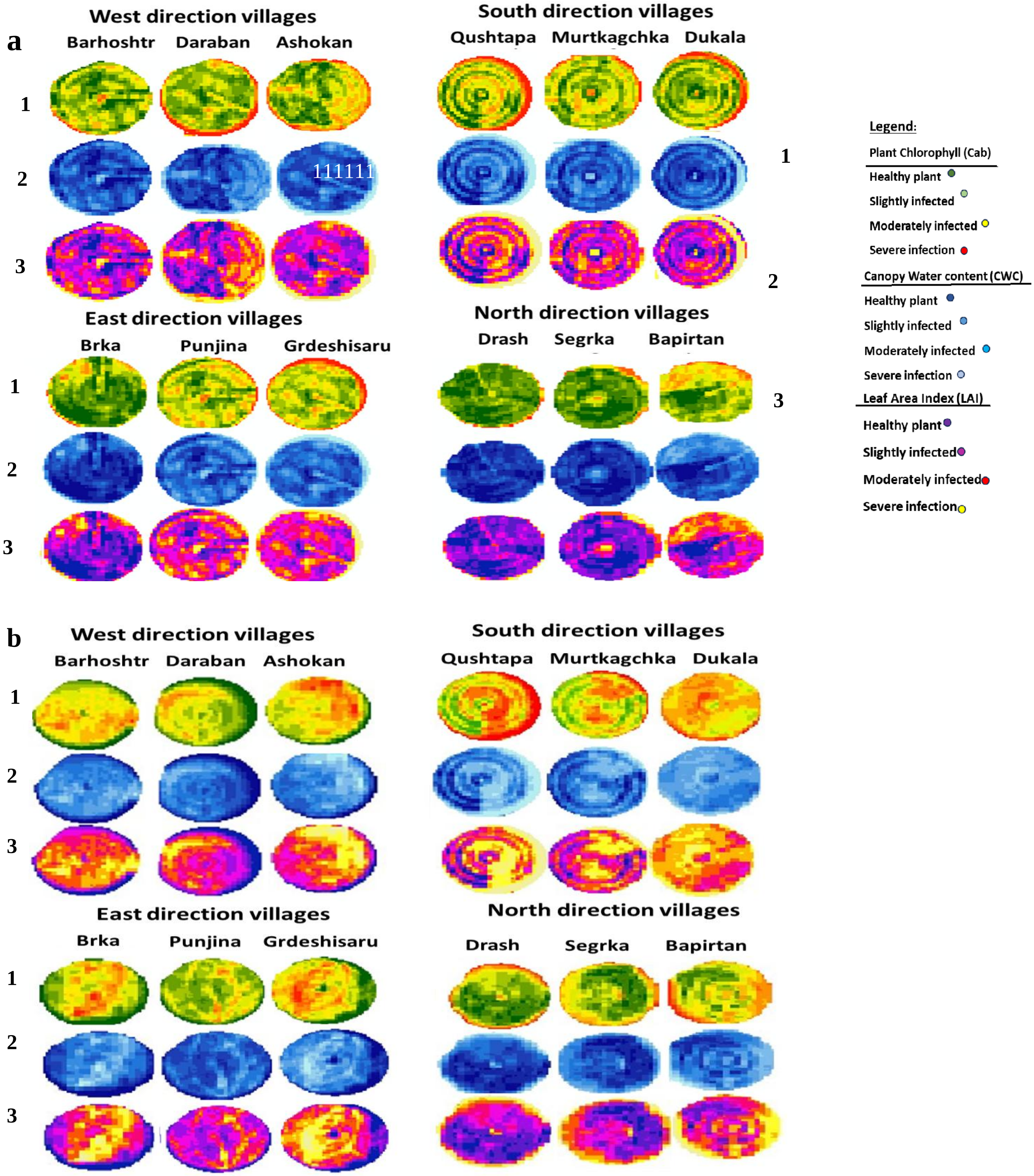

Figure 9: Arc map exhibit different levels of reflectance of Cab, CWC and LAI infested with *Anisoplia* sp. in various direction of Erbil Province (a) November 2022 and (b) January 2023.

3.4.3 Correlation between field collected and GIS data in some wheat biological properties

A Pearson correlation revealed that the obtained remote sensing data represent the field assay in the surveyed areas and thus, the severity of wheat crop infestation was negatively correlated with LAI, *r* = -0.729, *P* <.0001, the Severity of infestation (M=30.03, SD=11.94), and LAI (M=50, SD=730). However, the SPAD measured chlorophyll was positively correlated with Cab chlorophyll r=0.748**,** p <.0001, the SPAD chlorophyll (M=38.21, SD=14.01). Moreover, the amount of water content in wheat crop and the remote sensing CWC were positively correlated r= 0.815**,** p<.0001, the amount of water content (M=0.0041, SD=0.0022) and CWC (M=0.011, SD=0.0081)**.**

3.5 Soil analysis assay

3.5.1Correlation between the population density of Anisoplia larvae and some soil physical and chemical measurements

The Pearson correlation revealed that the population density of Anisoplia larvae in section 3.1.1. was strongly correlated with the soil texture, thus the population density was highly positively correlated with the sand texture, *r* = 0.938, *P* <.0001 , the population density (M=4.28, SD=2.50), and sand% (M=29.67, SD=10.20).While the population was weakly negatively correlated with both the silt%, *r* = -0.461, *P* =0.013 (M=38.25, SD=5.52), and the clay% , *r* = -0.674, *P* =.016 (M=32.17, SD=10.46). On the other hand, the population density of grain beetle was neither correlated with EC, *r* = 0.381, *P* =0.222, (M=0.916, SD=0.288), nor with the pH , *r* = 0.090, *P* =0.780 (M=7.916, SD=0.288). The population density of the beetle was moderately positively correlated with the percentage of organic matter in the soil *r* = 0.748, *P* =0.005, (M=1.416, SD=0.514) (Table 2).

Table 2: Physical and chemical properties of soil in various geographical locations of Erbil Province

Village names	Sand%	Silt %	Clay %	Soil Texture	EC dS/m	pH	OM %
Drash	19	44	37	Silty clay loam	0.6	7.78	1.05
Segrka	17	44	39	Silty clay loam	0.5	7.79	1.25
Bapirtan	19	42	39	Silty clay loam	0.7	7.87	1.04
Punjina	24.9	40.7	34.4	Clay loam	0.6	7.98	1.36
Grdeshisaru	23	35	42	Clay loam	0.7	7.83	1.39
Brka	25.8	41.6	32.6	Clay loam	0.7	7.89	1.37
Qushtapa	26	25	49	clay loam	0.6	7.67	1.75
Murtkagchka	34.9	35.7	29.4	Clay loam	0.7	7.68	1.67
Dukala	34.9	33.2	31.9	Clay loam	0.8	7.36	1.84
Ashokan	43	42	15	loam	0.6	7.73	1.45
Daraban	41	37	22	loam	0.7	7.83	1.54
Barhoshtr	47	38	15	loam	0.7	7.78	1.52

4. Discussion

Geographic Information Systems can decrease significant crop yield losses caused by agricultural insect diseases and pests by allowing the comparison of previous and present information through spatial maps, therefore enabling the application of integrated pest management accordingly (Rano et al., 2022). Hence, the innovative strategies in precision agriculture contribute to reducing the overall number of chemical pesticides and place a greater emphasis on more precise doses rather than randomly used conventional methods besides the excessive usage of chemical doses can pose risks to the environment and non-target species (Isenring, 2010, Sánchez-Bayo, 2021).

Furthermore, the effectiveness of these systems is contingent on the accuracy of the pest population monitoring technique that is utilized to be included in decision support systems and provides timely insights on the risk of an infestation of pests (Lima et al., 2020). The challenges of accurately implementing GIS are highlighted by the requirement for specialized expertise and ethical considerations with the use of sensitive data, even with the prospect of a thorough study of the modeling (Radha and Khwarahm, 2022).

The outcomes of this investigation contribute to the comprehension of the extent of economic damage that the grain beetle has inflicted. The spatial distribution of insect populations and their corresponding impact on wheat crops are key indicators for assessing the potential risk posed by this pest in various areas (Kokila et al., 2021, Achiri et al., 2024). The use of GIS techniques in managing *Anisoplia sp.* offers detailed insights into physical and biological interactions within metapopulation dynamics. It also aids in developing spatial models that predict future pest populations by identifying favorable habitat conditions. This data can help pest managers make more precise decisions about controlling pest populations across various locations and larger regional scales this is in alignment with (Hufkens et al., 2019, Ali et al., 2021).

The variation in *Anisoplia* population across the surveyed villages might refer to the soil texture and the preference for sandy soils and loamy soil which could provide optimal conditions for larval development as the soils facilitate easier burrowing for larvae which is critical for their survival. The larvae consume the cereal roots in the soil, while the adults predominantly destroy the wheat grain potentially causing substantial injury with the presence of 3-4 individuals per square meter in the fields results in significant economic damage (Yıldırım et al., 2013). The larvae inflict damage on several grasses, including wheat, barley, oats, and rye, thus soil management practices and regular monitoring are essential to mitigate their impact effectively (Brussaard and Runia, 1984, Hann et al., 2015). Furthermore, *Anisoplia* larvae demonstrate a preference for soils enriched with organic matter due to their optimal aeration and moisture levels, which create favorable conditions for larval development. The soils with elevated organic content are likely to attract females for oviposition, as they enhance the survival prospects of their offspring. As a result, organic matter significantly impacts the distribution and population dynamics of various soil-dwelling pests (Frew et al., 2016, Yadav et al., 2023, García-Atencia et al., 2024).

To a same extent, the variation in pest infestation in different directions is likely also attributed by environmental conditions, which play a significant role in influencing the dispersal and range expansion of the species. Consequently, villages in Western and Southern regions experienced more severe beetle infestations, while the Eastern and Northern regions faced less damage which might refer to the cold condition in the latter direction. Thus mild climates in (i.e. Western and Southern parts) are optimal conditions to the beetle's growth and development and this is in agreement with (Ozder, 2002) who stated that the distribution rates of *Anisoplia* sp. might reaches up to 72% on wheat crop depending on specific climatic condition. Therefore, due to the heavy beetle population in the above mild directions probably these fields will be subjected to an excessive application of chemical pesticides by local farmers which result in the emergence of insect resistance to the standard conventional pesticides that have been used in these areas (Khidr, 2018, Isawi et al., 2023).

Likewise, different agricultural practices such as the wheat variety and cultivation time can also account for variations in insect population density in different geographical locations (Rusch et al., 2010, Khidr, 2018, Ezaddin and Salih, 2022). As a result, in fields with a high population density of insects, the wheat crop was severely damaged in surveyed villages and the spatial analysis and insect distribution could assess the risk of pest development in large areas and this is in agreement with (Hay-Roe et al., 2016, Yuan et al., 2017, Paudel et al., 2021).

Chlorophyll a and b content (Cab) and leaf area index (LAI) are two important key parameters of remote sensing data for wheat crop and their quantitative inversions are important for growth monitoring and the field management of wheat(Ji et al., 2024). Consequently, evaluating wheat computed biological parameters i.e. the Cab chlorophyll which reflects the nitrogen present in the plant as lower levels can suggest nitrogen deficiency that might be caused by pest infestation or deficiency in fertilizer levels and thus by utilizing cab chlorophyll in remote sensing indices can optimize nitrogen application and reduces waste from excessive fertilizer and pesticide application (Duarte et al., 2015, Rano et al., 2022).

This is consistent with previous studies conducted on forest trees which exhibited that the chlorophyll maps accurately reflected the stress that the trees were experiencing as a result of beetle infestation when Sentinel-2 satellite data were employed in the experiments (Abdullah, 2019, Darvishzadeh et al., 2019, Liu et al., 2021). Additionally, the leaf area index in vegetation indices is indicative of the health of the crop as a lower LAI may indicate stressed wheat leaf from pest infestation, whereas a higher LAI may indicate healthy plant development and, consequently, a lower level of infestation. This can be used to more effectively apply pesticides, thereby reducing the pests (Yang et al., 2009, Motie et al., 2023).

Furthermore, current investigations have revealed that factors observable by satellite remote sensing, such as the modified normalized difference water index can affect the development of crop diseases and pest infestations (Luo et al., 2014, Deleon et al., 2017, Praveen and Sharma, 2020). GIS map with the different reflection of colors representing, nitrogen, Chlorophyll and water content in infesting and healthy wheat crop with the observed actions of the reflectance spectra in the visible region (Mashonganyika et al., 2021, Abdusamea, 2024). Also, this study can indicate stress caused by early and late infestation of *Anisoplia* sp. and this is in agreement with the results of earlier studies focused on stressed plants due to insect infestation (Hunt Jr et al., 2011, Abdullah et al., 2018).

It is relevant to highlight that the severity of the damage increased over an extended period, reaching its peak in February. This is in line with prior studies that have documented the appearance of *Anisoplia* sp. from November to late March in response to varying climatic conditions (Malhamchi, 2010, Kyrychenko et al., 2021). Additionally, the correlation coefficient between field and GIS data can be linked to a specific vegetation patch as several studies have Integrated GIS data with field observations to identify regions where insect pests impose considerable damage, facilitating tailored pest management measures and revealing the patterns of the pest distribution, damage and the stressed parts of the plant (Beckler et al., 2005, Liu et al., 2021, Hama and Khwarahm, 2023).

5. Conclusion

The study effectively highlights the distribution and impact of the grain beetle on wheat crops in Erbil Province by integrating traditional field surveys with GIS technology, it provides valuable insights into the varying infestation levels across different geographic locations, particularly observing significant infestations in the Western villages. The correlation between pest population density and both soil and crop biological indicators underscores the necessity for effective pest monitoring. Overall, the findings emphasize the importance of adopting a multifaceted approach to pest management, combining both traditional knowledge and modern technological advancements, to enhance the resilience of wheat production against such destructive pests.

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Conflict of interest

We declare that the work is done by the authors at Salahaddin University and all agreements have been disclosed and there are no any conflicts.

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