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Fundamentals of using Geographical Information Systems in predicting the distribution of *Helicoverpa armigera* (Lepidoptera: Noctuidae)

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Abstract. *Ruzmetrov R, Abdullaev I, Gandjaeva L, Matyakubov Z, Iskandarov A, Otaev O, Ibragimov S. 2022. Fundamentals of using Geographical Information Systems in predicting the distribution of* Helicoverpa armigera *(Lepidoptera: Noctuidae). Biodiversitas 23: 3251-3256.* This study aims to explore new ways to identify agroecological conditions that help in the occurrence of *Helicoverpa armigera* in cotton fields. Geographical data on soil salinity, mechanical composition, groundwater level, salinity, density of canals and drains, field Normalized Difference Vegetation Index (NDVI) coefficient of the field *Helicoverpa armigera* with the number of eggs regression was analyzed. The data were collected from the database of the GIS laboratory of the KRASS (Khorezm Rural Advisory Support Service) agro-consulting center, which was established with support from ZEF (The Center for Development Research) University of Bonn, Germany, and lancet satellite data in the calculation of NDVI. Data were analyzed with ArcGIS and R program. Occurrence of *Helicoverpa armigera* in cotton fields was found to be associated with high relative humidity and high stem length. Using the relative humidity of the air in the field and other agro ecological factors, it was found that the probability of remote distribution of cotton bollworm is more than 50%.

Keywords: Cotton bollworm, diffusion analysis, forecasting methods, groundwater, humidity, NDVI, temperature

INTRODUCTION

The manifestation of climate change has grown substantially from the last century, it leads to various hazardous problems such as global warming, storms, heavy rains, change of land use patterns, drier climate and forceful migration of millions of organisms. Insects have played key roles in terrestrial ecosystems, yet they have been ignored in conservation approaches, however, they are slowly making their way into the biodiversity studies. Moths are affected by minute changes in climate and also show changes in reproduction, mortality, dispersion and development (Dar and Jamal 2021a). Moths as ecological indicators is established globally, covering a wide range of current environmental issues like habitat fragmentation, climatic changes and deforestation, etc. Moths play an important role in the natural ecosystem and are sometimes notorious as agricultural pests (Dar and Jamal 2021b).

Lepidoptera is the second largest order of Class Insecta. It comprises of two sub-orders, i.e., Moths (Heterocera) and Butterflies (Rhopalocera), consisting of about 124 families Kristensen et al. (2007). The Noctuidae, commonly known as owlet moths, cutworms or armyworms, are the most controversial family in the superfamily Noctuoidea because many of the clades are constantly changing, along with the other families of the Noctuoidea. It was considered the largest family in Lepidoptera for a long time, but after regrouping Lymantriinae, Catocalinae and Calpinae within the family Erebidae, the latter holds this title now. Currently, Noctuidae is the second largest family in Noctuoidea, with about 1089 genera and 11,772 species. However, this classification is still contingent, as more changes continue to appear between Noctuidae and Erebidae (Regier et al. 2016).

Scoops (family Noctuidae) is one of the numerous groups of insects that live in various natural and climatic zones. The Scoops fauna of the natural landscapes of the Khorezm oasis is represented by 69 species belonging to 9 subfamilies and 44 genera (Bekchanova 2021). In the course of their evolutionary development, their individual representatives have become widespread in the cotton agrobiocenosis. The polyphagy inherent in scoops with the use of leaves, roots and fruiting organs of plants characterizes them as one of the most dangerous pests of cotton. Despite the progress made in protecting cotton from harmful cutworm species by chemical and biological means, they still remain a great threat to cotton plants. The use of these means could not provide the necessary ecological regulation of the relationship between plants and entomofauna.

In the Khorezm region, which is one of the northern regions of Uzbekistan, cotton is grown on an average of 45-50% of the total area, which is more than other crops (Tischbein et al. 2013). The most dangerous pest of cotton in the region is *Helicoverpa armigera* (Hübner, 1805). Biological methods are used in the pest control system. In the system of biological control of cotton bollworms, one of the factors determining its effectiveness is the prediction of the source of the pest and the state of their egg larvae

(Schowalter 2017). Species like *Trichogramma chilonis Trichogramma pintoi* and *Bracon hebetor* are used for prophylactic control against pest eggs, while *Chrysopa carnea* is used to control young larvae and eggs (Lakshmi et al. 2016).

Cotton bollworm eggs hatch in 2-6 days, depending on temperature, and larvae in 23-33 days (Huang et al. 2015). this figure may vary depending on the temperature (Cunningham and Zalucki 2014). The years in which eggs are mass-produced are difficult to control because of their high resistance to insecticides (Ouyang et al. 2014; Moshe et al. 2018). Determining egg-laying foci when they are more likely to reproduce and applying *Trichogramma* spp. to those areas will help to control their population. To do this, it is necessary to identify areas that are convenient for the caterpillar to lay eggs. In the traditional way, the number of cotton bollworms falling into pheromone traps was studied by placing one controller on 50 hectares to determine the areas where cotton bollworms caused the most damage. This method requires a lot of labor and costs. The fact that the temperature in the region is very high during summer days and that the fields are far from the settlements also makes pheromone traps unexplored. Under such conditions, the caterpillars in some fields multiply and spread to other fields, which can lead to severe damage to cotton plants and reduced yields. Therefore, it is necessary to develop methods based on modern information technologies and some achievements have been made in this regard (Tischbein et al. 2013; Schowalter 2017).

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This article examines methods for predicting the relative humidity of the field air in the field and other areas with a high probability of remote spread of tapeworms using specific agroecological factors.

MATERIALS AND METHODS

The experiments were conducted in five districts of the Khorezm region. Khazarasp, Kushkupyr, Yangibazar, Urgench and Khanka, in the north part of Uzbekistan and these districts that differs from other regions of Uzbekistan with its unique soil and climatic conditions (Figure 1).

The climate is sharply continental with very cold winters (up to -41ºC), hot (+25 and +30º) and very hot summers (up to +45ºC). The average annual temperature of the oasis is +13.9ºC, and +15ºC in the southern part of the oasis (Abdullaev et al. 2020). Due to its location in the desert zone, the climate is dry. Agro-horticultural practices include the cultivation of cotton, rice, wheat, fruits and vegetables with irrigation mainly. Saline groundwater is close to the soil surface and varies at a depth of 0.6-3 meters. There are special irrigation systems and a drainage system to drain the sewage. Such a farming system requires constant control of natural factors for obtaining high yields from crops. Classical methods are used for continuous monitoring (Latchinisky et al. 2013; Ruzmetov et al. 2020).

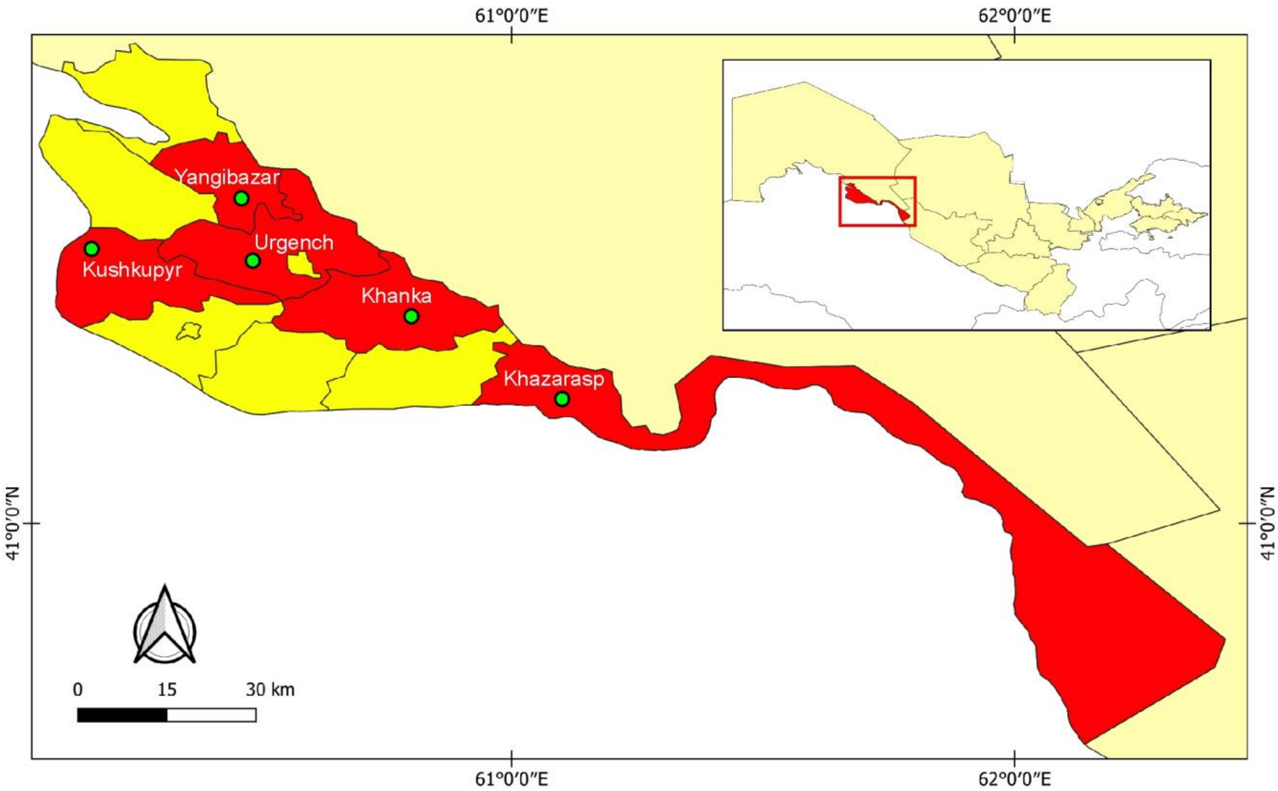

Figure 1. Geographic locations of specimen collectionin Khorezm region, Uzbekistan

During the study, the maximum number of larvae of *Helicoverpa armigera* per 100 cotton plants was obtained and compared. The amount of perennial irrigation water allocated to the region for 2013-2018 was taken from the reports of the Left Bank Irrigation Systems Department. The methods adopted to study the distribution of caterpillars in the fields were carried out (Noor-Ul-Ane et al. 2015; Schowalter 2017). RapidEye consists of 5 satellite systems along the Earth's orbit with 5 spectral zones with a geometric accuracy of 6.5 meters (blue zone 440-550, green 520-590, red 630-685, red and near-infrared zone 690-730 and near-infrared 760-50 nm). Data from the Landsat satellite were analyzed based on RapidEye data, which had a very high degree of accuracy (Hüttich et al. 2014).

In pixel and object-based classification, Landsat image 6 spectral channels (1-6) and Landsat 8 image 7 spectral channels (1-7), as well as plant indices and multi-zone data, were analyzed using statistical methods. The analysis was performed using R, ENVI 4.5 and ArcGIS 10.0. A total of 3 algorithms, nonlinear differential algorithms i.e. RF (random forest), SVM (support vector machine) and MLC (maximum similarity classifier) methods, were used to classify space images based on minimum ground size (pixels) using ArcGIS program. Classification of agricultural crop species was carried out on the basis of satellite images of crop fields in the R environment and using the ArcGIS program. These classification algorithms were used to isolate cotton crop areas. Normalized Difference Vegetation Index (NDVI) was determined using the following formula based on data obtained from the Landsat 8 OLI satellite (IDB 2022; USGS 2022) of the cotton plant field (Hüttich et al. 2014).

$$NDVI = \frac{nir - red}{nir + red}$$

ANOVA model was used for the statistical analysis of the collected data. The research used the database of the KRASS agro-consulting center established with support from ZEF (The Center for Development Research), University of Bonn, Germany.

Atmospheric humidity and temperature measuring devices (MISOL/Wireless weather station) were installed at the height of 1 meter in the cotton field at a distance of 5 km. The development of all *Trichogramma* spp. is very similar. Being an egg parasite, the female drills a hole through the chorion and deposits its eggs within the egg of the host. The internal pressure of the egg forces a small drop of yolk out of the oviposition hole. Females feed on this yolk, which increases their longevity under laboratory conditions. Female parasitizes from one to ten eggs per day or from ten to 190 during her life. Large females parasitize more eggs than smaller females. The number of eggs laid per host egg may vary from 1 to 20 or more, depending upon the size of the host egg. However, in sugarcane, in which moth borer eggs are small, generally, 1 or 2 parasites develop per egg (Jumaev and Rakhimova 2020). The parasitoid wasps *Trichogramma chilonis*, *Trichogramma pintoi* species and Bracon hebetor Soy were propagated in biolaboratories and distributed to the farmers for weekly release in the fields (Tabebordbar et al. 2022). In areas where the number of *Helicoverpa armigera* was increasing, farmers treated the area with the drug Avaunt 150 EC (Emulsifiable concentrate) (Hüttich et al. 2014).

RESULTS AND DISCUSSION

The number of eggs of *Helicoverp armigera* encountered in the study area of the Khorezm region during the period of 2013-2018 was analyzed. The number of eggs was found to vary between the years (Figure 2). There were more complaints from pests in the area by farmers located closer to the river, around large canals. To confirm these data, we conducted a comparative analysis of the amount of water used by the region for irrigation during the infestation of *H. armigera* with the number of eggs laid by *H. armigera* during the year for 2013-2018. In 2013, the amount of water allocated to the region was 3200 mln. m^3. In the same year, the maximum annual number of pest eggs per 100 plants was found in the district Yangibazar. In 2014, the total amount of water allocated to the region decreased to 31.50 mln. m^3, of the four districts surveyed, only the cotton fields in the Yangibazar district were found to have *H. armigera* eggs.

In 2015, the total amount of irrigation water allocated to the region increased to 3700 mln. m^3. Cotton in the fields of all the districts studied the number of eggs was observed to increase compared to other years. In 2016, a sharp decrease in the amount of water allocated to the region also led to a decrease in the number of cotton bollworm eggs found in the fields and it was found only in the fields of the Yangibazar district. In the province, an increase or decrease in irrigation volume between 2013 and 2017 was observed to be associated with a number of *H. armigera* caterpillars (Figure 3).

Most studies have reported that increased humidity during the summer months (Narayanamma et al. 2013) may lead to the development of cotton bollworms. In the Khorezm region, the impact of irrigation water on the relative humidity of the air has a certain effect. Female caterpillar moths prefer more convenient areas for laying eggs in the evenings. High humidity has a positive effect on the life expectancy and successful mating of moths (Tischbein et al. 2013; Schowalter 2017). We studied the differences in atmospheric humidity and temperature in the fields of the Khorezm region and its relation to the number of caterpillars in these fields.

Hygrometric indicators were analyzed with the help of data from small farms in "Sarapayon bioservice" of Khanka district, "Davron" of Khiva district, "Rozzoq" of Khanka district. For the study, mini-meteorological stations were installed.

The results showed that not all fields had the same hygrometric index. The dependence of the number of cotton bollworm eggs on the relative humidity is shown in Figure 4. In order to more accurately observe the relationship of factors in the diagram, the data on the average relative humidity % of the air were multiplied by a factor of 0.1. It was found that cotton bollworm eggs were observed in the fields with a relative humidity of more than 40%. As the humidity in the fields, 2,6,7,8 increased, an increase in the number of cotton stalks in the field was also observed. Experiments have shown that the average humidity in the fields of a single farmer varied over large ranges. This means that the probability of insect pests appearing in some fields on a single farm will also vary.

Studies have been conducted to predict data on the effects of temperature and humidity on the distribution of cotton bollworms (Noor-Ul-Ane et al. 2015; Lakshmi et al. 2016). The adopted forecasting system was based on the existing large-scale meteorological stations in the region, covering an area of 6.1 million hectares (Anon 2022). In the age of science and technology, it is necessary to put into practice new scientific advances in order to collect data in the forecasting system. During the development of the current forecasting system, meteorological stations were complexly structured and located over a large area. However, these meteorological stations predicted for large areas and were unable to detect pest outbreaks in smaller areas. Because small-scale meteorological stations are inexpensive, they can be placed densely (for example, 1 per 10 hectares), with fewer errors when interplaying data between meteorological stations. Our experiments showed that high moisture depends on the weather and the height of the crops in the field. Humidity can be high in tall cotton fields. The high moisture content of cotton fields also depends on the agronomic and other factors applied to the neighboring field and the field crops being studied (Hüttich et al. 2014).

As indicated by Schowalter (2017), cotton bollworms appear in areas with high humidity. NDVI (Normalized Difference Vegetation Index) was studied in 85 fields of the Khorezm region in the study of high-growing areas, taking into account the increase in atmospheric humidity due to their transpiration due to the high green mass of plants in fields with high NDVI. We analyzed the correlation between the data on the number of eggs and the NDVI indicator of cotton bollworm and 30% correlation was found. Our results showed that a number of factors affect the distribution of cotton bollworm in the field, which include plant condition, irrigation conditions, soil moisture, temperature, soil layer structure, parasitism, predation, etc. (Figure 5).

Figure 2. Distribution of caterpillars in the conditions of Khorezm region Number per 100 plants (in the conditions of 4 districts)

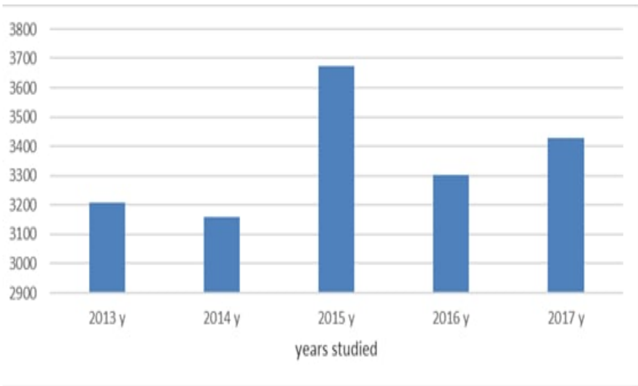

Figure 3. The amount of irrigation water supplied during the growing season of crops for Khorezm region

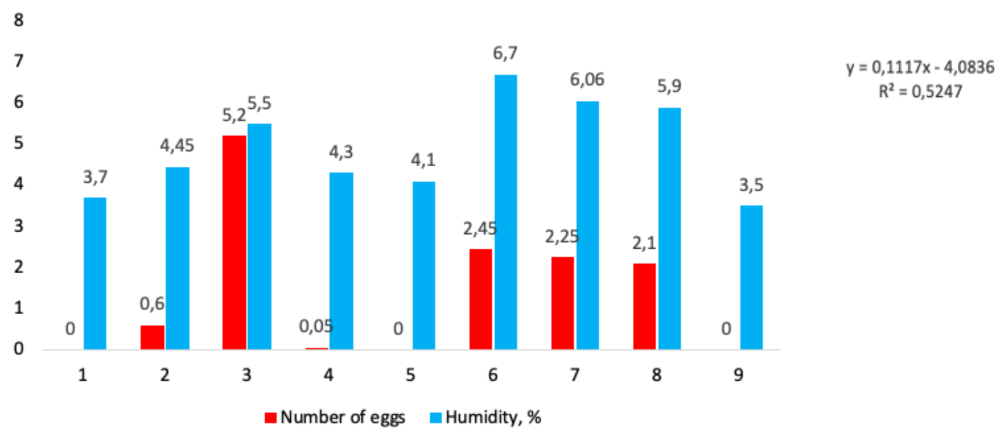

Figure 4. Relationship of atmospheric humidity (expressed as % × 0.1) of the field and the no. of eggs of cotton bollworm *Helicoverpa armigera* per plant

There are data on the dependence of groundwater level on several factors, such as soil mechanical composition, irrigation regime (Matyakubov et al. 2020). The present study found that the dependence of the relative humidity on the field was higher. Therefore, in predicting the distribution of cotton sediments, we took irrigation networks and drainage ditches, soil mechanical composition, and groundwater level as factors influencing atmospheric air humidity. According to our experiments, the physiological state of cotton plays an important role in the formation of cotton bollworms. Among the factors influencing the physiological state of cotton was NDVI.

In the regional context, mainly the 2nd generation of cotton bollworms are reported to cause more damage to cotton, which coincides with the flowering phase of cotton (Jumaev and Rakhimova 2020). Larvae feed on generative organs. Considering that the presence of a large number of generative organs can also attract cotton bollworm, soil fertility score was taken as one of the factors predicting the pest. Regression analysis was conducted and the probability of encountering the pest eggs in the field was calculated and found to be related to the number of eggs encountered in the real field (Figure 6). According to the results of the multivariate analysis, the prevalence of cotton bollworm was predicted with a 52% probability. It was found that the correlation between the NDVI of the field and the number of caterpillars was 30%. Based on the results obtained, the agroecological factors were theoretically classified as shown in Table 1. As the density (meters/ hectare) of canals and drains increases, the probability of laying cotton bollworm eggs in the field also increases. The groundwater level can be 0.5-3 meters in regional conditions. In surface fields, evaporation increases with the increase in soil moisture.

It was found that the surface fields provide favorable conditions for the caterpillar to lay eggs. As a result of the mineralization of groundwater, the cotton plants become short, resulting in less generative organs. This factor can reduce the chances of the caterpillar laying eggs.

The mechanical composition of the soil is expressed by the amount of very fine soil particles in the soil. It was accepted that the increase of fine particles in the soil could ameliorate the physiological condition of the cotton, thus also leading to the increase in the number of caterpillars. It was accepted that the cotton bollworm tends to lay more eggs in such fields because it damages the generative organs. NDVI assumed that plant biomass would also increase the likelihood of caterpillar eggs laying as the field's high transpiration leads to an increase in humidity in the field.

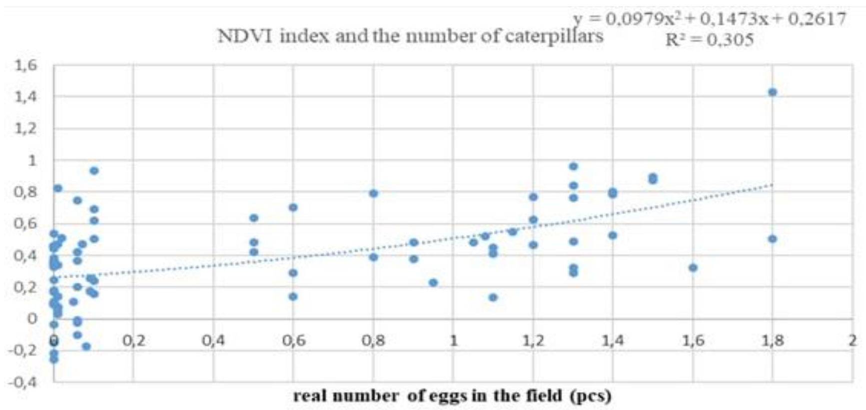

Figure 5. Correlation between field NDVI index and caterpillar number

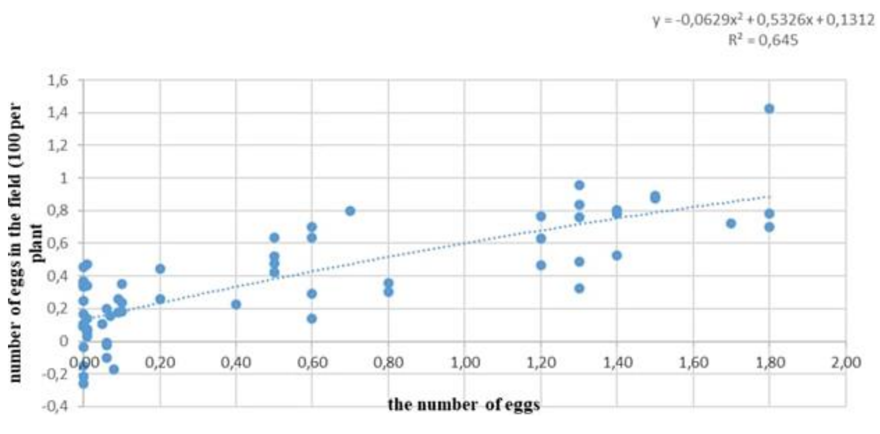

Figure 6. Correlation between agroecological factors and the numbers of larvae

Table 1. Scale for classification of agroecological factors in assessing the probability of development of cotton bollworm

Factors	Classification				
	Very convenient	**Convenient**	**Average**	**Low**	**Unconvenient**
Channel density, m / ha^{-1}	> 8	8-6	6-4	4-2	<2
Drainage density, m / ha^{-1}	> 40	40-30	30-20	20-10	<10
Groundwater level, m	<0.5	0.5-1	1.0-1.5	1.5-2	> 2.0
Groundwater mineralization, g /L	<1.0	1-3	3.0-5.0	5-10	> 10.0
Mechanical composition of soil, clay particle size, %	> 60.0	45	30	20	10.0
Soil quality, points	> 70.0	70-60	60-50	50-40	<40
NDVI, plant biomass	> 0.7	0.7-0.5	0.5-0.4	0.4-0.3	<0.3

In conclusion, it was found that the humidity of the fields was conducive for laying eggs of cotton bollworm moths. Humidity was found to be uneven in the areas of the Khorezm region. Factors such as field channels, drainage density, groundwater level and their mineralization, soil mechanical composition, soil fertility score, NDVI, which affect the field air humidity and physiological state of the cotton, can be analyzed and predicted for the field-based upon standard GIS platform.

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