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EFFECTS OF SOIL SALINITY ON CEREAL CYST NEMATODES (*HETERODERA*) AND POTATO GOLDEN NEMATODES (*GLOBODERA*)

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ABSTRACT

The extension of durum wheat (*Triticum durum* L.) and potato (*Solanum tuberosum* L.)areas in the Chelif plain in Algeria, which is subdivided into three parts, the high, middle and lower Chelif, it has resulted in the appearance of several bio-aggressors, the most dreaded of which are the cereal cyst nematodes *Heteodera* and the potato nematodes *Globodera.* The lower Chelif plain is characterized by high average electrical conductivity, pH and limestone content, however, the effect of soil physic-chemical parameters, in particular salinity, on the structure of the cyst nematode community is still poorly understood. The nematological analysis of 31 samples in durum wheat fields and 38 samples in potato fields and spread over the three (3) sectors of the Chelif plain allowed to conclude that these two types of nematodes are present in all sectors of the plain. The frequency of infestation of *Globodera spp* is total (100%) in the two sectors, the high and middle Chelif and about 50% in the lower Chelif. The frequency of infestation of the nematode *Heterodera spp* reaches 100% in the high Chelif, followed by the middle 90%, and finally the lower 50%. The statistical analysis shows significant correlations of the three soil parameters electrical conductivity, water content and total nitrogen with both types of nematodes. The correlation of electrical conductivity has a negative significance of about 77% with the frequency and degree of infestation of *Globodera* and 65% with the frequency and degree of infestation of *Heterodera*, Soil moisture and total nitrogen are positively correlated with both types of nematodes in Algeria Chelif plain.

Keywords: soil physico-chemical parameters, *Triticum durum*, *Solanum tuberosum,* Chelif plain Algeria.

Introduction

Cereals and potatoes are staple crops and sources of nutrition for humans in many developing countries, they are the main sectors of agricultural production in Algeria. The Chelif valley covers an area of approximately 400 km^2 (Saidi *et al*., 1999), and constitutes a preponderant place in Algerian agricultural production. However, cyst nematodes are pests that seriously affect cereal and potato production. In the case of potatoes, these nematodes feed on the roots and cause severe drops in production yields (Fleming and Turner, 1998; Djebroune *et al*., 2020). The area reserved annually for this crop is 85,000 hectares, or about 30% of the total area devoted to market gardening (Omari, 2011). *Globodera* species are native to the Andes (Evans and Stone, 1977) and were introduced into Europe around 1850 (Jones, 1970). From there, they have spread through human activity to many areas. These nematodes have considerably disrupted potato production in Algeria since 1953, when they were first discovered following the introduction of potato seeds of British origin at the end of the Second World War (Frézal, 1954). In Algeria, in 2019, cereal production was estimated at 41,2 million tons for an area of 3 385 560 ha, according to the statistical services of the Algerian agricultural services directorate. Among the biotic agents that limit cereal production, cyst nematodes of the genus *Heterodera* cause considerable losses and represent a major constraint to cereal production intensification (Chabert *et al*., 2012; Dababat *et al*., 2015; Righi *et al*., 2017).

Among the biotic agents that limit cereal production, cyst nematodes of the genus *Heterodera* cause significant negative impacts on cultivated cereals (Chabert *et al*., 2012; Dababat *et al*., 2015, Nicol *et al*., 2007). Cyst nematodes of the genus *Globodera* represent a major constraint to the intensification of potato production (Peter *et al*., 2001), with the potential to cause more than 70% yield losses (Turner and Subbotin 2013, Pinheiro *et al*., 2015). This problem has been underestimated as long as medium- and low-yielding cultivars have been grown; on the contrary, it appears to be very serious for new cultivars, which are much more efficient, but also much more vulnerable (Assia *et al*., 2017). Soil salinity is a limiting factor for crop productivity and constitutes a major problem in the management of irrigated perimeters and soils in the Sahara in Algeria (Munns, 1993).

More than 20% of irrigated soils are affected by salinity (Douaoui *et al*., 2007).

The extension of cultivated areas in the plains of the Chelif (High, Middle and Lower), which are nevertheless areas with high production potential. This has resulted in the occurrence of several pests, the most serious of which are the cereal cyst nematode (*Heterodera*) and the golden potato nematode (*Globodera*), which is a plant-parasitic nematode considered as a quarantine nematode of the Solanaceae family, such as potato.

Tirchi *et al*. (2013) conducted a survey on the in Algeria revealed that potato cyst nematodes (PCN) and cereal cyst nematodes (CCN) are widely distributed in several potato and cereal producing regions of the country. PCN populations were identified as *Globodera rostochiensis* and *Globodera pallida*, occurring separately or in mixed populations. Two species of CCN were detected. *Heterodera avenae* was found in four localities, while *H. hordecalis* was only found in one locality in association with H. potato cyst nematodes (PCN), are damaging to potato in various countries (Turner, 1998). These pests constitute the second group of the top 10 plant nematodes of scientific and economic importance (Grenier; Mimee, 2017) resulting in estimated annual losses of 9% of the world's potato production (Turner and Subbotin, 2013). In Algeria, cereal cyst nematodes (CCN) of the genus *Heterodera* are increasingly emerging as important pests. They attack all cereals, but to varying degrees depending on the region, crop, climate, and physical and chemical properties of the soil (Rahem, 2020). CCN have a major impact on cereal yield reduction worldwide (Handoo, 2002; Namouchi-Kachouri *et al*., 2005; Akar *et al*., 2009; Toumi *et al*., 2013; Ahmadi and Tanha, 2014). A study of the management of nematode stands by the biological functioning of soils was developed in Sudan-Sahelian cropping systems in Senegal by Kadet *et al.* (2000) demonstrated that some abiotic factors (exchangeable base contents) are therefore likely to be manipulated to modify the specific structure of the nematode stand and mitigate their pathogenic effect. Tao *et al*. (2020) also studied the contrasting effects of N deposition and increased precipitation on soil nematode communities in a temperate forest, finding that N deposition positively affected nematode communities by increasing nematode abundance in some bacterial and fungal nematodes.

Although PCN and CCN have been shown to be widespread in various areas of the Chelif plains (Tirchi *et al*., 2013), little is known about their effects in soils physicochemical characteristics especially salinity since that it affects a large area of this plain (Walter *et al*., 2001). This aim of this study is to contribute to highlight the existence of these two types of cyst nematodes in the three sectors, high, middle, and low of the Chelif plain. It searches for highlighting the state of infestation by these two nematodes of the cultivated soils of potato and durum wheat in the plain. This work is based on two types of regions, one characterized by soils with high level on salinity (like those located at the INRA station of H'madna in the lower Chelif zone), and other one without or with low level of salinity at the middle Chelif area.

Materials and Methods

Study site

The Chelif plain covers an area of about 400 km^2 and extends from east to west in the eastern and sublittoral part under a semi-arid Mediterranean climate (Figure 1). It is subdivided into three parts, the high, middle, and low parts, with respective altitudes of 300, 160 and 70 meters and rainfall of 470 to 390 mmper year. The soils of these plains are formed in quaternary alluvium (Boulaine, 1956, 1957; Daoud, 1983) and are mostly poorly differentiated, calcareous, of variable texture, sometimes hydro morphic, with the presence of vertic or calcimagnesic soils. The lower Chelif is characterized by the presence of numerous saline soils (Saidi *et al*., 1999) (Figure 1).

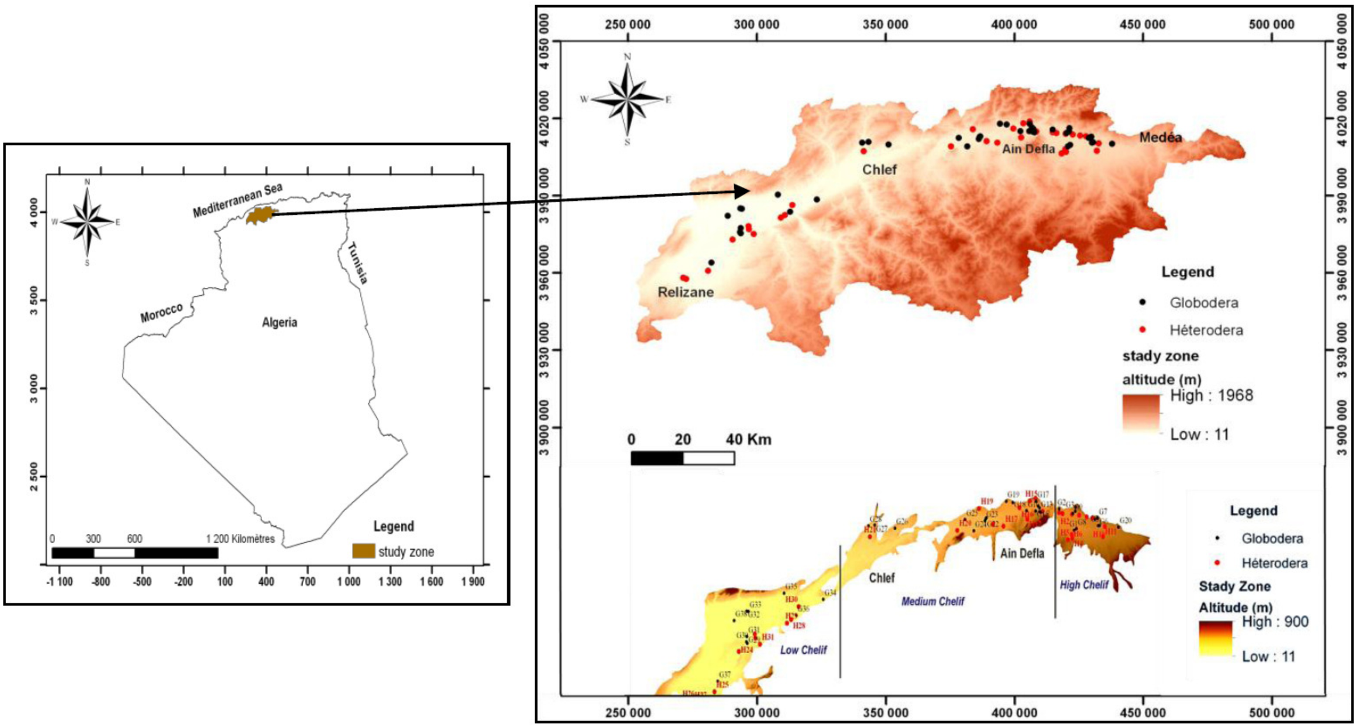

Fig. 1 : Geographical location of the high, the middle and the low parts of the Chelif plain with the sampled points.

Sampling

Surveys were carried out among potato growers in different areas of seasonal potato cultivation in Algeria between April and June 20018 and among durum wheat growers in the bolting phase in March and April 2018. The study covered the entire length of the Chelif plain and variability in the degree of salinity was sought to show a wide range of effect. According to Merny and Luc (1969), the technique used is that of the aggregate sample, which consists of taking incremental samples from several points in each plot, which are then combined into a single aggregate sample.

In each plot we took 25 incremental samples of about 100g along the two diagonals of the plot, which were mixed into a global sample of about 2,5 kg representative of the plot (to compensate for the heterogeneity of the nematode distribution). A subtotal of 2,5 kg was collected around the root systems at 15-20 cm depth after removing the high 5 cm, in each plot we took a sample of about 1 kg from 5 to 25 cm reserved for the analysis of soil parameters (Figure 1).

Thirty-one samples were taken for the detection of *Heterodera* cysts in the plots of durum wheat fields in the different plains of the Chelif, of which 11 samples were taken from the High Chelif, 10 from the Middle Chelif and 10 from the Low Chelif (average surface area of each plot is two hectares). The same principle was applied in the potato fields for the detection of *Globodera* cysts, of 38 samples, 10 samples from the High Chelif, 18 from the Middle Chelif and 10 from the Low Chelif.

Extraction, nematode counting, and soil analysis

Each soil sample was thoroughly mixed. Cysts were extracted from 500 g subsamples using the modified Fenwick box technique (Fenwick, 1940; Smiley, 2011) and mature cysts retained on the 250 µm sieve were collected with a dissecting needle under a stereomicroscope. Species were identified based onthe morphological characteristics (Handoo, 2002). The cysts collected *Heterodera ssp* were generally ovoid to lemon shaped, but had different sizes (Haddadi and Mokabli, 2015). The cysts collected *Globodera spp* were generally round with a reddish-brown color called cysts 0.3 to 0.9 mm in diameter in soil (Richard and Sawyer., 1972); (Ritter, 1971; Stone, 1973).

The cysts were counted in 500 g of soil. The enumeration of solid and empty cysts of *Globodera spp* and *Heterodera spp* is done under a binocular magnifying glass. Solid cysts are recognized by their turgid appearance and dark but sometimes light color, while empty cysts are identified by their light color which, on contact with a drop of water, appears to be devoid of eggs or juvenis, or by crushing the cysts to check whether the cysts are solid or empty. For each soil sample in the study areas, the population density of NCCs is the number of *Globodera spp*. and *Heterodera ssp*. cysts in each 500 g of dry soil, and the number of eggs and second instars juveniles/ 1g of soil. Eggs and J2 were obtained by crushing the cysts and counted using a counting tablet.

Analyses of the physico-chemical parameters of the soil on the samples reserved for each plot studied. These samples are characterized by the granulometric fractions after decarbonation and sieving, clay (A), silt (L) and sand (S), the electrical conductivity (EC) measured on an extracted soil/water ratio of 1/2,5, the total limestone (Ca) determined by the Bernard Calcimeter method and the organic matter (OM) by the Anne's method.

Data processing and analysis

Two groups of variables were considered in our study, variables related to the pests (infestation status) and variables related to the physico-chemical parameters of soil in the studied plots, the geographical location of the samples was delimited and divided according to the three parts of the Chelif plain: high, middle, and low. The number of cysts was calculated for the five sub-samples and expressed per Kilogram of soil (Nbr CN. g/soil), the degree of cyst infestation (DIC) was expressed as the number of eggs and J2 in one gram of soil E + J2. (g of soil). To investigate the relationship between soil physico-chemical parameters and infestation status, the data were subjected to mean, standard deviation and principal component analysis using IBM SPSS Statistics version 21. The cartographic representations of the location and variations were made by ArcGIS Version: 10.0.

Results

Physic-chemical characteristics of the tested soils

The general statistics of the physic-chemical characteristics of the potato and durum wheat plots soil according to the different sectors indicate the predominance of soils with a basic pH around 8generally calcareous, with an organic matter content between 1 and 2% and a clayey-silt texture (Tables 1 and 2).

Table 1 : General statistics of the different physico-chemical parameters of the soil samples in the potato plots according to their origin within the Chelif plain, Algeria.

Parameters	Arithmetic mean				Standard deviation			
	High Chelif	Middle Chelif	Low Chelif	Average	High Chelif	Middle Chelif	Low Chelif	Average
EC $dS.m^{-1}$	3,19	2,72	8,23	3,36	0,20	1,16	4,52	3.91
pH	7,66	7,77	7,85	7,76	0,16	0,23	0,23	0,22
Humidity (%)	19,55	19,51	19,04	19,43	0,35	0,59	0,84	0,80
$CaCO_3$ (%)	15,65	17,72	24,70	19,01	7,48	7,62	1,70	7,32
Total N (%)	0,19	0,19	0,17	0,18	0,01	0,01	0,01	0,01
OM (%)	1,61	1,43	1,10	1,38	0,19	0,35	0,09	0,32
Clay (%)	32,00	27,00	32,00	28,00	4,69	6,54	4,39	5,89
Silt (%)	43,00	43,00	43,00	44,00	2,74	8,48	2,66	6,20
Sand (%)	25,00	30,00	25,00	28,00	2,47	10,66	5,73	8,42

The samples from the lower Chelif plain are distinguished by electrical conductivity and limestone content, and low averages for organic matter, except for electrical conductivity, where the low standard deviations reflect a lower variability of results in this region compared to the middle and high Chelif. Both soils from potato and durum wheat plots in the high, middle, and lower plain show similar value in the pH, soil humidity, $CaCO_3$, Total N, Organic Matter, Clay, Silt and sand (Tables 1 and 2).

Table 2 : General statistics of the different physico-chemical parameters of the soil samples in the durum wheat plots according to their origin within the Chelif plain, Algeria.

Parameters	Arithmetic mean				Standard deviation			
	High Chelif	Middle Chelif	Low Chelif	Average	High Chelif	Middle Chelif	Low Chelif	Average
EC $dS.m^{-1}$	1,47	1,56	7,64	3,48	0,32	0,28	4,75	3,91
pH	7,70	7,71	7,77	7,72	0,18	0,23	0,33	2,49
Humidity (%)	22,44	21,59	18,95	21,04	2,14	1,97	1,21	2,32
$CaCO_3$ (%)	14,95	15,20	24,90	18,24	7,27	7,55	1,85	7,58
Total N (%)	0,19	0,19	0,17	0,18	0,00	0,00	0,01	0,12
OM (%)	1,68	1,27	1,25	1,40	0,25	0,36	0,25	0,34
Clay (%)	32,00	27,00	27,00	29,00	4,44	6,18	4,39	5,45
Silt (%)	43,00	43,00	46,00	44,00	2,60	4,52	2,66	3,54
Sand (%)	27,00	30,00	27,00	27,00	6,38	8,09	5,63	6,87

Nematological examination

Globodera solid cysts were detected in all the potato plots surveyed in the high and middle Chelif plains where the frequency of infestation reached 100% in both sectors. In the low Chelif plain five (5) plots out of ten (10) were infected which implies a frequency of 50% infestation (Table 3). The durum wheat plots sampled at the level of the high Chelif plains were all infected by solid cysts of *Heterodera*, an infestation frequency of 90% was detected in the middle Chelif plains and 50% in the low Chelif plains (Table 3).

Globodera solid cysts were detected in all the potato plots surveyed, in the high and middle Chelif plains where the infestation frequency reached 100%, in the low Chelif plains five plots out of ten were infected which implies an infestation frequency of 50% (Table 3).

Table 3 : Frequency of infestation of in the different sampled potato plots by *Globodera* and durum wheat by *Heterodera* according to their origin within the Chelif plain, Algeria.

Chelif sectors	Sampled plots	Infected plots	Frequency Infestation (%)
	Globodera/Heterodera		
High Chelif	10/11	10/10	100/100
Middle Chélif	18/10	18/09	100/90
Low Chélif	10/10	05/05	50/50

The durum wheat plots sampled in the High Chelif plains were all infected with *Heterodera* solid cysts (infestation frequency of 100%), an infestation frequency of 90 % was detected in the middle Chelif plains and 50% in the lower Chelif plains.

Large numbers of *Globodera* cysts were collected during our surveys in the potato plots. However, empty cysts were most abundant in all areas of the Chelif plain (Figure 3). The highest average number of empty cysts was observed in the high Chelif (79,24 cysts/kg soil) and the lowest number was recorded in the lower Chelif (67,88 cysts/kg soil). The highest average number of full cysts was recorded in the middle Chelif (49,04 cysts/kg soil), followed by the high Chelif (37,36 cysts/kg soil), a low density of 8,34 cysts/kg soil of solid cysts was recorded in the lower Chelif even though the total number recorded was high (70,86 cysts/kg soil) (Figure 3). The total number of *Globodera* was highest in the high and in the middle Chelif, and lowest in the low Chelif plain (Figure 3).

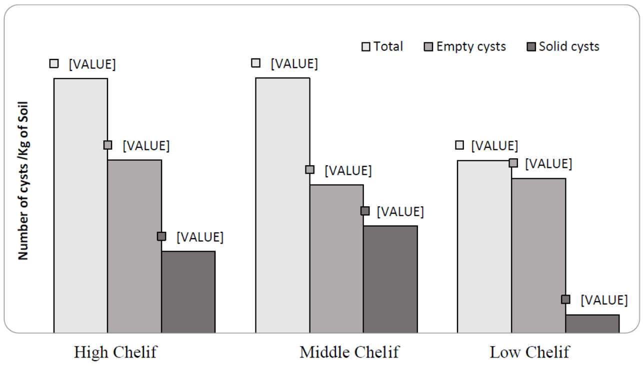

Fig. 3 : Average numbers of cysts (empty, solid and total) of *Globodera spp* (in potato plots) according to their origin within the Chelif plain, Algeria.

Concerning the density of *Heterodera* spp cysts found in the durum wheat plots, the density of empty cysts was high in the high and middle Chelif plains: 91,31 and 55,24 cysts/kg soil (Figure 4), in contrast to the lower Chelif plain where there was not much difference between the density of empty and solid cysts (6,75 and 4,24 cysts/kg soil). The highest total number of *Heterodera* was in the high and middle Chelif and the lowest in the lower Chelif.

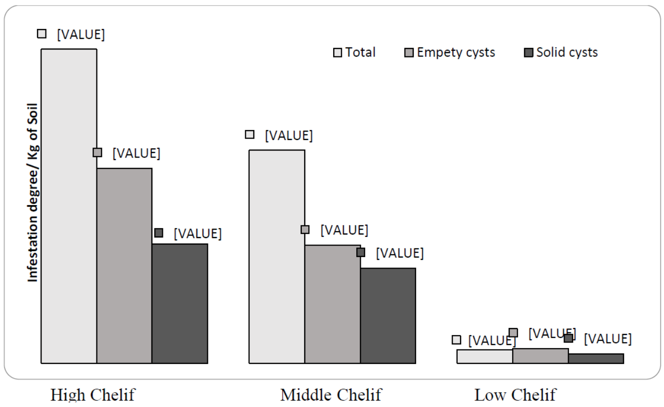

Fig. 4 : Average numbers of cysts (empty, solid, and total) of *Heterodera spp* (in durum wheat plots) according to their origin within the Chelif plain.

The degree of infestation is calculated according to the number of eggs (E) or juvenis (J) in one gram of soil (Mugniery, 1975; 1982). The calculation of the average infestation levels of potato plots by *Globodera* nematodes for each sector of the Chelif plain, revealed (Figure 5) that the most infested Chelif plain is 14,70 E+.J2/g of soil, the threshold of harmfulness (estimated at 10 larvae/g by Mugniery, 1975) was reached or even exceeded, followed by the high Chelif plain with 8,14 E+J2/gof soil.

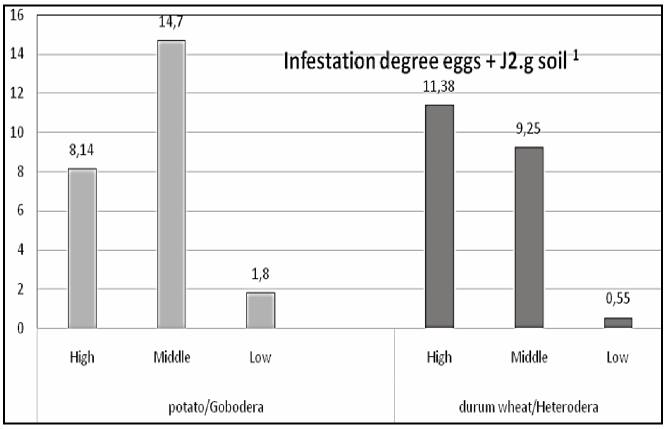

Fig. 5 : Average of infestation degree of *Globodera spp* in potato plots and *Heterodera spp* in durum wheat plots, according to their origin within the Chelif plain, Algeria.

The lowest one was observed in the low Chelif plain with 1,88 E+ J2/g of soil and in the Ain Defla plot (140 E+ J2/ kg of soil).For the state of infestation of the durum wheat plots by *Heterodera spp* within the different sectors of the Chelif plain, the threshold of harmfulness is exceeded in the high Chelif it reaches 11,38 E+ J2 /g of soil, followed by the middle Chelif 9,25 O+ J2 /Soil, a low degree of infestation is observed in the low Chelif sector (0,55 E+J2 /gof soil).

Ordinary kriging makes it possible to carry out a spatial interpolation, it makes possible to predict the value taken by a natural phenomenon on a site starting from point observations of this phenomenon on the neighboring sites (Matheron, 1963). The interpolation of the data using ordinary kriging gives us a general idea on the estimated infestation status of the cyst nematodes *Globodera* and *Hetrodera* on the plain of Chelif in these three sectors. The state of infestation by the nematode *Globodera* is very high in the middle Chelif with more than 10 L2+ Eggs/g of soil followed by the high and low Chelif with less than 10 Eggs+ J2/g of soil(Figure 6). The same remark has been made for the state of infestation by the nematode *Heterodera* but in a slightly lower way (Figure 6).

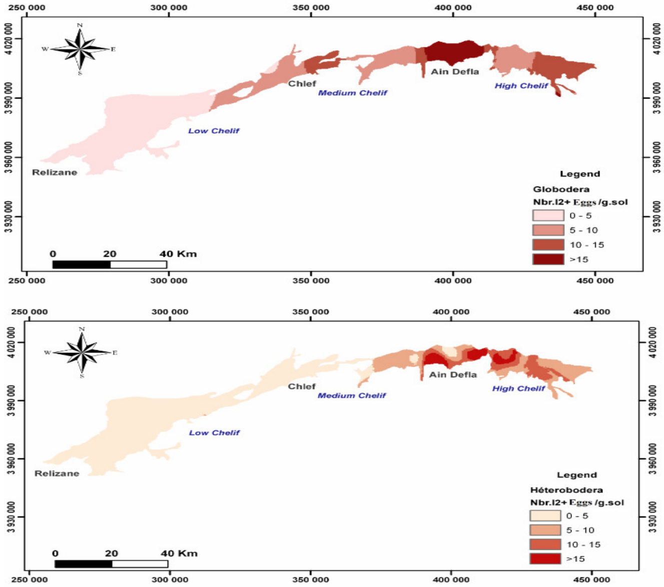

Fig. 6 : Map for estimating the degree of infestation of the Chelif plain by *Globodera and Heterodera spp* cyst nematode (ordinary Kegeage method).

3.3 Principal component analysis

The existence of differences between the lower Chelif sector and the two other sectors (high and middle Chelif) on the physicochemical parameters of the soil, particularly salinity and the states of infestation by the two types of cyst nematodes *Globodera* and *Heterodera,* led us to apply a principal component analysis to highlight the correlation between the states of infestation and the physicochemical parameters of the soil.

The correlation coefficients between soil parameters and frequency number of solid cysts per kilogram of soil (SC/Kg of soil), degree of infestation of second in star larvae + number of eggs in grams of soil (l2+eggs.g of soil) indicate relationships between the infestation status of the potato plots (Table 4) and certain soil parameters: electrical conductivity, soil moisture and percentage of total nitrogen. A significant negative correlation was marked between electrical conductivity and the frequency of infestation (SC/Kg of soil) where the negative significance reached the threshold of 77% and 64% for the degree of infestation (l2+eggs. g/soil). The second positively significant correlation is recorded between the percentage of soil moisture and the frequency of infestation where the degree of correlation is in the range of 67% for the frequency of infestation and 66% for the degree of infestation, total nitrogen is positively correlated with the frequency and the degree of infestation (64 and 56%).

Table 4 : Linear correlation matrix between soil parameters and the frequency and degree of infestation of potato plots by the nematode *Globodera spp* (significant values above 0.5 are underlined).

Correlations	ECd $S.m^{-1}$	pH	W (%)	$CaCO_3$ (%)	N (%)	OM (%)	TC/ Kg of Soil	EC/Kg of soil	SC/Kg of soil	12+EGGS/g of soil
EC $dS.m^{-1}$	1,00									
pH	0,08	1,00								
W(%)	-0,63	-0,14	1,00							
$CaCO_3$ (%)	0,38	0,43	-0,27	1,00						
N (%)	-0,63	-0,51	0,54	-0,54	1,00					
OM (%)	-0,41	-0,12	0,33	-0,29	0,45	1,00				
TC/ Kg of Soil	-0,63	-0,37	0,52	-0,39	0,53	0,50	1,00			
EC/Kg of soil	-0,17	-0,23	0,11	-0,15	0,16	0,33	0,77	1,00		
SC/Kg of soil	-0,77	-0,29	0,67	-0,35	0,64	0,36	0,60	-0,05	1,00	
12+EGGS/g ofsoil	-0,64	-0,17	0,66	-0,48	0,55	0,31	0,58	0,06	0,82	1,00

The same soil parameters that correlated with the frequency and degree of infestation of *Globodera spp* in the potato plots also correlated with the frequency and degree of infestation of *Heterodera spp*, (Table 4 and 5), namely electrical conductivity, moisture, and percentage of total nitrogen in the soil. A negative correlation was found with the frequency and the degree of infestation of *Heterodera spp* cysts in the durum wheat plots, but to a lesser extent than the correlation of frequency and degree of infestation of *Globodera spp* cysts in the potato plots, the negative correlation with the frequency of infestation was about 55% and 51% for the degree of infestation. Between soil moisture and percentage of total nitrogen, the same remark is recorded for *Globodera spp*. with a positive correlation. For the percentage of total nitrogen the correlation is of the order of 62 % with the degree of infestation and 65% with the frequency of infestation.

The principal component analysis (PCA) allows to highlight the different characteristics of the soils and the degree of infestation by cyst nematodes. This method also allows the quantitative data to be processed in a table and diagrammed in a matrix, and to highlight non-linear relationships between variables.

Table 5 : Linear correlation matrix between soil parameters and frequency, degree of infestation of durum wheat plots by the nematode *Heterodera spp* (significant values above 0,5 are underlined).

Correlations	EC $dS.m^{-1}$	pH	W(%)	$CaCO_3$(%)	N (%)	OM (%)	TC/ Kg of Soil	EC/Kg of soil	SC/Kg of soil	12+EGGS/g of soil
EC $dS.m^{-1}$	1,00									
pH	-0,03	1,00								
W(%)	-0,40	-0,14	1,00							
$CaCO_3$ (%)	0,40	-0,09	-0,37	1,00						
N (%)	-0,69	-0,18	0,58	-0,53	1,00					
OM (%)	-0,34	-0,22	0,27	-0,07	0,30	1,00				
TC/ Kg of Soil	**-0,60**	-0,20	0,54	-0,52	0,69	0,36	1,00			
EC/Kg of soil	**-0,58**	-0,18	0,45	-0,47	**0,65**	0,31	0,96	1,00		
SC/Kg of soil	**-0,55**	-0,16	**0,60**	-0,50	**0,62**	0,36	0,91	0,78	1,00	
12+EGGS/g of soil	**-0,51**	-0,25	**0,76**	-0,39	**0,65**	0,49	0,76	0,60	0,88	1,00

Table 6 of the total variance explained by the PCA between the variables corresponding to the degree of *Globodera* infestation and the various soil characteristics indicates that most of the information is carried on the first two axes of the components (64%), which implies that we can read the relationships and the correlation on two axes.

Table 6 : Quality of representation of the different variables on the two axes of the component's matrix (soil parameters and degree of *Globodera* and *Heterodera* infestation).

Parameters	*Globodera* component		*Heterodera* component	
	1	2	1	2
EC $dS.m^{-1}$	-0,822	0,225	-0,717	0,241
pH	-0,429	-0,364	-0,222	-0,79
Humidity(%)	0,748	-0,289	0,719	0,069
$CaCO_3$(%)	-0,595	-0,083	-0,596	0,512
N (%)	0,815	-0,023	0,829	-0,106
OM (%)	0,579	0,256	0,474	0,483
TC/Kg of Soil	0,822	0,438	0,911	0,012
EC/Kg of soil	0,348	0,856	0,881	0,2
SC/Kg of soil	0,847	-0,387	0,935	-0,023
12+EGGS/g of soil	0,812	-0,327	0,857	-0,063

The values of the components in Table 6 show that all the variables except for the empty cysts are well represented on the first component (axis 1) whose quality of representation is higher than 0,5 on the axis 01. The reading of the information on the first component (Figure 7) shows two groups of variables, one group is composed by the variables representing the degree of infestation (SC/Kg of soil; 12+EGGS/g of soil), total nitrogen, soil moisture, organic matter, these variables are positively correlated with each other and have negative correlations with the second group variable which are the electrical conductivity and the percentage of total limestone. The graphical representation of the principal component analysis of the variables related to the degree of *Globodera* infestation in the soils planted in the Chelif plain (Figure 7 and 8) shows that there are significant correlations of an antagonistic relationship between the electrical conductivity, the percentage of total limestone and the degrees of infestation of the soils by *Goblodera*, the positive correlations reported which represent a synergistic relationship between the total nitrogen, the organic matter and the moisture of the soil and the degrees of infestation by *Globodera* cysts.

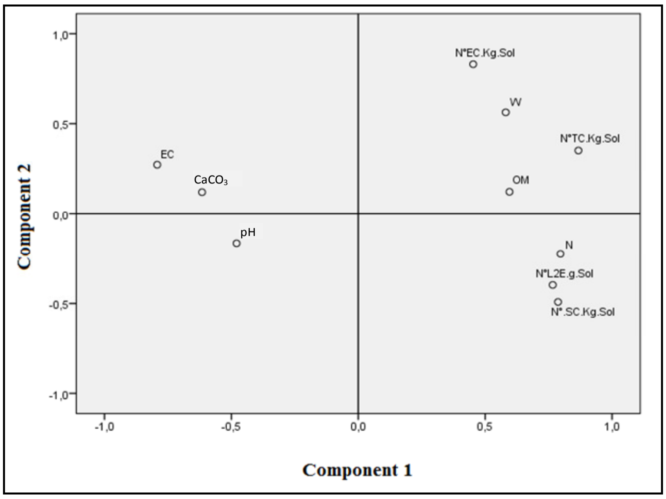

Fig. 7 : Component diagram between the different variables (soil parameters and *Globodera spp* infestation degrees in potato fields).

The total explained variance which represents the information of the principal component analysis between the variables of the degrees of infestation of the soils planted with durum wheat in the Chelif plain and the different variables of the physicochemical parameters of soils, we can notice that the majority of the information of the analysis is carried on the first two components (67%) whose quality of representation is well on the first axis for the majority of variables (Table 6). The information on the first component indicates antagonistic correlations between one group of variables represented by the degree of infestation, total nitrogen and soil moisture and the second group represented by the electrical conductivity and the percentage of total limestone, a positive correlation was recorded between total nitrogen, moisture and the degree of infestation by *Heterodera* cysts.

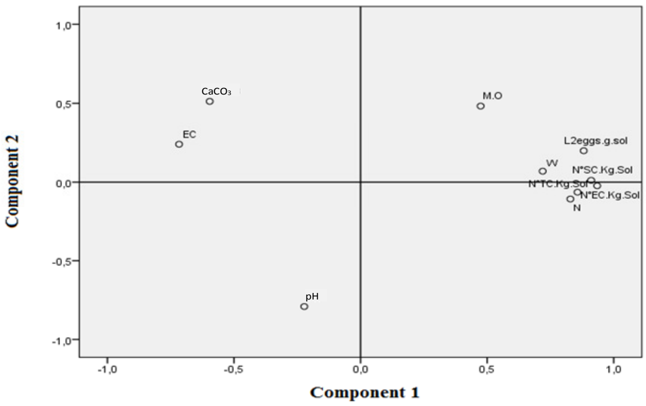

Fig. 8 : Diagram of the components between the different variables (soil parameters and *Heterodera spp* infestation levels in durum wheat fields)

Discussion

In Algeria, the Chelif plain is an area with great potential for production of both cereals and vegetables. Potatoes and wheat are important crops in Algeria. The results of the hematological analyses of 38 samples in potato plots in the three sectors of the Chelif plain, indicate that the plots in the two sectors of the plain (high and medium) are totally infected (100%) which differs from the low Chelif sector where the frequency of infestation is 50% (Table 3). In the study of Djebroune (2013), in the region of Ain Defla, which is part of the middle Chelif, the frequency of infestation is a little less (77, 08% of the surveyed plots are infested), it is clearly more important than in the case of our study (100%). However, the degrees of infestation calculated (0-10 Eggs+J2/g soil) by the same author were less important than those obtained in our study (1,88-14,70 Eggs+J2/g soil). In the same way, the threshold of harmfulness was reached in the sector of the high Chelif 14,70 (Eggs+J2/g of soil) contrary to the middle Chelif where the degree of infestation is low:1, 88% (Figure 5). This study also showed that even many soil parameters are similar in the three sectors other factors such as cultivar (Djebroune *et al*., 2020), soil type, climatic conditions, especially temperature and humidity and many others can affect potato production.

The results of nematological analyses of 31 samples in durum wheat plots distributed in the three sectors of the plain of Chelif revealed that 100% of the plots studied were infested in the upper Chelif, 90% in the middle Chelif and 50% in the lower Chelif (Table 4).

It is interesting to recall that at the Mediterranean scale, the results of the work of Alabed *et al*. (2004) show that cereal cyst nematodes are widespread in several places from north to south and in the desert areas with a percentage ranging from 30 to 100%. In Egypt, cereal cyst nematodes were found in five areas of El Ismailia with an average frequency of 79,4% and an average population density of 29 cysts, 10 Eggs+ D2/g soil (Baklawa *et al*., 2015).

In the case of our study, the average infestation level reached 11,38 Eggs+D2/g soil in the upper Chelif, which is the maximum level of harmfulness, followed by the middle Chelif and finally the lower CHELIF with 0,55 Eggs+D2/g soil (Figure 5). The work reported by Djetti *et al*. (2018), indicates that the *Heterodera* species is present in the whole cereal-growing area in Algeria. The most important presence concerns the areas of Draa Semar and Djendel (cereal plains located in the upper Chelif) with respectively 17,32 and 11,48 cysts/100 g soil. However, the lowest infestation was recorded in the fields of Ras Elouad, Sidi Mbarek and Sedraia (cereal-growing areas located in the lower Chelif) with respectively 0,12 - 0,32 and 0,4 cysts/100 g soil.

Differences between the lower and the other two sectors were found on soil physicochemical parameters especially salinity (Table 1 and 2) and infestation states by cyst nematodes *Globodera* and *Heterodera*. This led us to apply a statistical principal component analysis to highlight the correlation between infestation states and soil physicochemical parameters. The results obtained indicated correlations of three soil parameters (Electrical Conductivity (EC), percentage of total Nitrogen (N) and soil moisture content (W)), Xueliang *et al.* (2020), showed that soil nematode communities were related to high soil organic matter content, total nitrogen, electrical conductivity. According to Novaretti (1995), the organic matter content into the soil creates favorable conditions for the multiplication of natural enemies to nematodes, and to promoting the formation of organic substances, such as volatile fatty acids, which may have nematicidal action. Furthermore, soil organic matter had important effects on spatial distribution of both plant-parasitic and free-living nematodes in the soil (Barros *et al*. 2017). The correlation matrices indicate a negative correlation of electrical conductivity with the degree of infestation by the *Globodera* nematode at 77% and with the degree of infestation by the *Heterodera* nematode at a slightly lower value of 55% (Table 5 and 6). A positive correlation between the two soil parameters total nitrogen and moisture with the degree of infestation by *Globodera* and *Heterodera* cyst nematodes was found to vary between 60 and 65%. The other soil parameters were excluded from our analyses as the correlation values were not significant, a scattering of points was observed, as the degrees of variation between the different soils sampled in the three areas of the plain were low. We noticed that in some plots a significant number of cysts were collected in kilogram of soil, but the estimated infestation rate reached the threshold of harmfulness even though the textural analysis (Tables 1 and 2) indicated globally, a clay-loam texture for the studied plots. These results are not consistent with the results of Schneider and Mugniery, (1971) who reported that light, aerated and porous soils are more favorable to the development of these nematodes than heavy soils. Even with data from Rojas & Cardona (2018) showed that sand content, porosity, calcium, and phosphorus, have a strong relationship with the presence of *Globodera* spp.

This study is an approach to an integrated control of potato cyst nematodes *Globodera* spp. and cereal nematodes *Heterodera* spp. in the three parts of the Chelif plain (high, middle, and lower) located in northern Algeria. The control of these nematodes requires the mapping of their distribution and the knowledge of the factors that govern their development. To this end, regular monitoring and surveys are essential to detect infested areas.

The study of the geographical distribution and the evaluation of the infestation status of the different plots by these parasites revealed that the infestation is confined in all parts of the plain for both types of cyst nematodes (*Globodera* and *Heterodera*) but by different degrees, the most infected area by *Globodera* potato nematodes is the middle Chelif by 14,70 Eggs+ J2/g of soil followed by the lower Chelif area with 8,14 Eggs+ J2/g of soil, finally a low infestation (1,88 Eggs+ J2/g of soil) was observed in the lower Chelif area. Concerning the nematodes of cereals *Heterodera* the most infected zone is the high Chelif by a degree of infestation which reaches the threshold of 11,38 Eggs+J2/g of soil then the zone of medium Chelif by a degree of 9,25 Eggs+J2/g of soil and the zone of low Chelif is the least infected (0,55 Eggs+J2 /g of soil).

In the regions where the parasite was detected, several factors contributed to its development: the type of binary rotation (potato-cereal), often applied in the surveyed plots, is not suitable to control this group of parasites which are able to remain in the soil for several years. The interaction of these factors with environmental factors (climatic and edaphic conditions) would be the cause of the difference in the state of infestation between the different locations surveyed. So, studies about the morphological taxonomy and molecular analysis should be conducted to identify the species of *Globodera* and *Heterodera* in this places. This identification is important to know about the control measures to crops culture rotation and potential hosts plants.

The number of cysts collected was considerably different in the three parts of the Chelif plain. To contribute to the study of the influence of physicochemical factors on the horizontal distribution of cysts in the soil, three factors that influence both types of nematodes *Globodera* and *Heterodera* were retained Electrical Conductivity, pH and limestone content, however, this study showed a remarkable relationship between soil salinity in particular and total limestone content ($CaCO_3$) with the distribution of number of solid cysts in kilograms of soil for the all three parts of the Chelif plain.

Conclusion

The cysts nematodes *Globodera* spp from potatoes plantation soil has a frequency of infestation total (100%) in the high and middle Chelif and about 50% in the lower Chelif plain.

The cysts nematodes *Heterodera* spp. from durum wheat cultivation soil has a frequency of infestation of 100% in the high Chelif, followed by the middle 90%, and the lower 50%.

The electrical conductivity, the moisture and the total nitrogen show significant correlations with *Globodera* and *Heterodera*;

The electrical conductivity has a negative significance of about 77% with the frequency and degree of infestation of *Globodera*, and 65% with the frequency and degree of infestation of *Heterodera*,

The soil moisture and total nitrogen are positively correlated with both types of nematodes in Algeria Chelif plain.

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Abbreviations

EC $dS.m^{-1}$: electrical conductivity. Deci-Siemens perMeter

$CaCO_3$ (%) : Percentage of total limestone

OM (%) : Percentage of organic matter

N (%) : Percent of total nitrogen

TC/Kg of Soil : Total number of cysts in kilograms of soil

EC/Kg of soil : Number of empty cysts in kilograms of soil

SC/Kg of soil : Number of solid cysts in kilograms of soil

12+EGGS/g of soil : number of second instar larvae + number of eggs in grams of soil

W (%) : soil humidity

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