Biological and Applied Environmental Research
Vol. 6(1): 68-80, 2022
https://doi.org/10.51304/baer.2022.6.1.68
ISSN: 2002-6153
Biol. Appl. Environ. Res.
www.baerj.com
editor@baerj.com

Mapping of Plant-Parasitic Nematode Using GIS Technology in Tainal Watershed, Sulaimaniyah Province, Iraq

Akram M. Abdulrahman
Agricultural Research Directorate, Sulaimaniyah, Iraq

Corresponding author: absrh2010@gmail.com

Abstract The present experiment was conducted to evaluate soil samples which had been taken from depths ranging from 0-30 cm in greenhouses planted with different vegetables such as cucumbers, tomatoes, peppers and eggplants in 24 agricultural sites in 19 villages. GIS application was used to make maps showing the results of a field survey that was conducted. The experiment was conducted for an area of 12 km^2 in the Tainal Plain, west of Sulaimaniyah Province. Nearly 30% of the soil of the greenhouses were heavily infected. Plant analysis showed that the characteristics of ash, fat and moisture were significantly affected as a result of infection with nematodes. The spread of root-knot nematode juveniles in the villages of Al-Mahmoudia, Kani Pengsharma and Kani Shaya was 706, 695 and 622 per 250 g of soil. In tissues of the studied plants, the highest nitrogen content was 68.2 mg in Ziyeka, 60.4 mg in Gawani and 59.7 mg in Ali Bzaw. Phosphorus concentrations were highest in Kani Shaya, Shwankara and Ziyeka (25.5, 25.3 and 23.1 mg, respectively). Warmizyar had 91.8 mg of potassium, Kani Shaya had 78.6 mg and Kani Big had 71.6 mg. The calcium concentrations in Ziyeka, Gawani and Mewk were 54.5, 48.4 and 47.7 mg, respectively.

Keywords: Root-knot nematode, *Meloidogyne incognita*, Plant analysis ArcGIS map, GIS coordinates

Introduction

In the past few years, *Meloidogyne javanica*, a root-knot nematode, had infected at least 3000 greenhouses in Iraq's Bazian Plain, Sulaimaniyah Province. Root-knot disease was caused by several species of the genus *Meloidogyne*. It was a parasitic nematode that makes its home in the roots of affected plants. There are around 98 known species within this genus (Jones et al., 2013). *Meloidogyne* species can survive in both hot regions and short winters throughout the planet. The root-knot nematode was one of the most damaging families of parasitic nematodes (Gill & McSorley, 2011). These nematodes are pests of nearly all major crops. Furthermore, *Meloidogyne* species are responsible for around 5% of worldwide crop yield loss each year (Karajeh, 2008). Farmers and other plant producers have long referred to it as "the nematode" illness (Mankau, 1980), because of the significant production decrease and visible root-galling signs caused by these pests. Depending on the species, nematodes are wormlike invertebrate creatures that can be found in marine, freshwater or terrestrial environments. Plants, other nematodes

Received Sep. 25, 2021, accepted Dec. 19, 2021

and their eggs, fungi, protozoans, bacteria, tardigrades and insect larvae are all possible food sources for nematodes (Freckman & Caswell, 1985).

Giné et al. (2014) showed the effects of *M. incognita* and *M. javanica* on cucumber, the maximum multiplication rate and equilibrium density of root-knot nematodes on cucumber and yield losses, and the relationships between relative leaf chlorophyll content and relative cucumber dry top weight biomass in response to increasing nematode densities.

GIS is an effective tool for analyzing, comprehending and projecting huge and complex data sets on crop output, productivity, land use, socioeconomic aspects and a range of agro climatic and environmental data (Seif-Ennasr et al., 2020). Several attempts have been made to employ anti-fungus to control the root-knot nematodes. Following soil preparation before planting with peat, tomato root irritation caused by *M. javanica* was greatly decreased (Sharon et al., 2007). The use of bran from *Bacillus* 251 as a bio-control agent of *M. incognita* on tomatoes, as detailed by Kiewnick & Sikora (2006), resulted in a significant reduction in egg production.

The drop in recent decades appears to be due to pathogenic agents as well as seasonal fluctuations. Plant diseases lowered worldwide output by more than 20% on average each year; nevertheless, isolated areas may suffer losses of 50% to 100% owing to one or more pests (Dhaliwal & Koul, 2007). Plant-parasitic nematodes are critical biological constraints in almost all types of agricultural plants all over the world, and they cause considerable losses in chilli production (Moon et al., 2010).

Any change in the biological components of ecological setup causes environmental deterioration. Many nematicides have been deregistered, resulting in pollution of the biosphere, highlighting the need for innovative techniques to combat nematodes and, as a result, improve agricultural yield. Farmyard manures, composts and botanical residues are all widely utilized in diverse crops as organic sources of nutrients. The best available option in integrated nutrient management programs is the complementary use of biofertilizers and organic manures in appropriate combinations with chemical fertilizers. This increases output, reduces fertilizer input costs, enhances the effectiveness of additional fertilizers and improves soil health at the same time (El-Sherif et al., 2007).

The aim of this research was to utilize a GIS to characterize soil types, soil texture and pH in relation to nematode incidence, significance and dispersion.

Material and Methods

Soil Sample Taking for Nematode Analysis

Nematode samples were taken from 20-25 cm depth throughout the summer season, cleaned and sanitized the shovel after each use, then the samples were placed in bags for analysis by using the sieving method.

Root-Plant Sample Taking for Analysis

1. Samples of roots were collected from diseased plants in greenhouses. Plants with infected roots were cut down. The fresh weight of these samples was calculated.
2. ArcGIS 10.1 application (WGS 1984_UTM_Zone_38N) with project coordinates system was used to create maps.

Table 1: Procedure of nematodes analysis.

No.	Materials	Source of procedure
1	20-mesh sieve (833 µm aperture)	Zuckerman et al. (1981)
2	200-mesh sieve (74 µm aperture)	
3	325-mesh sieve (43 µm aperture)	
4	Coarse sieve (1 cm aperture)	
5	Two stainless steel bowls or plastic buckets	
6	250 ml beaker	
7	600 ml beaker	
8	Coarse spray wash bottle or tube attached to faucet	

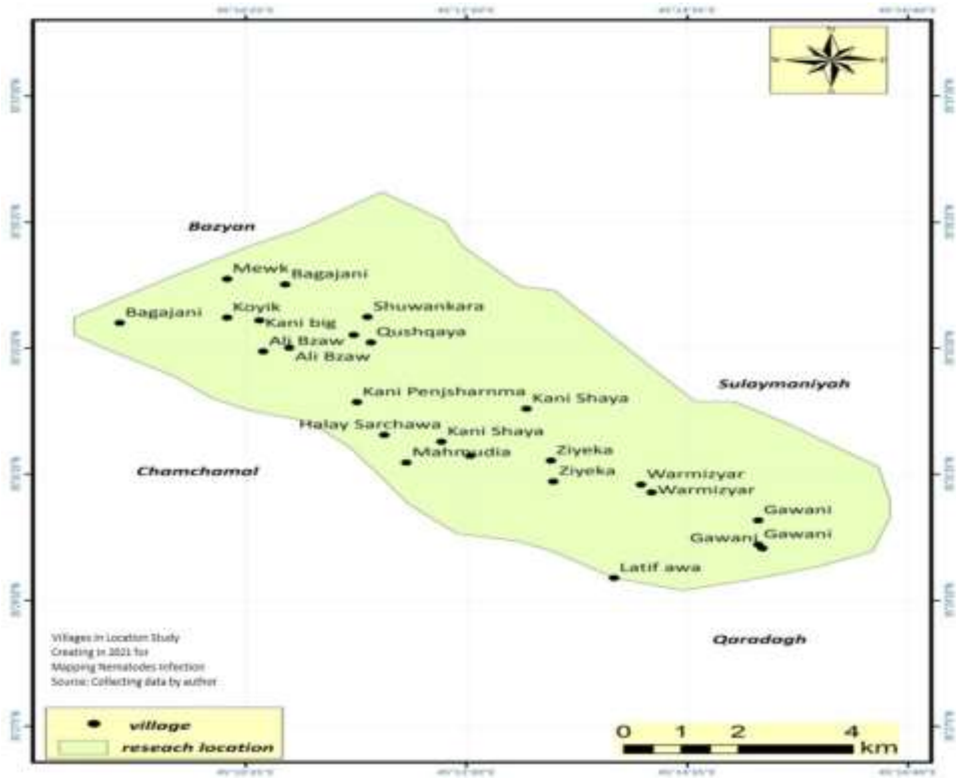

Figure 1: Villages covered in the present study.

Table 2: GIS coordinates for locations in Tainal Watershed.

Locations no.	Village name	Latitude	Longitude
L1	Bagajani 1	N 35.57	E 45.17
L2	Mewk	N 35.57	E 45.17
L3	Bagajani 2	N 35.56	E 45.15
L4	Koyik	N 35.56	E 45.17
L5	Kani Big	N 35.56	E 45.17
L6	Shuwankara	N 35.56	E 45.19
L7	Tui Awlia	N 35.55	E 45.19
L8	Qushqaya	N 35.55	E 45.19
L9	Ali Bzaw 1	N 35.55	E 45.18
L10	Ali Bzaw 2	N 35.55	E 45.17
L11	Kani Penjsharnma	N 35.54	E 45.19
L12	Kani Shaya 1	N 35.53	E 45.21
L13	Kani Shaya 2	N 35.52	E 45.20
L14	Halay Sarchawa 1	N 35.52	E 45.20
L15	Halay Sarchawa 2	N 35.53	E 45.19
L16	Mahmudia	N 35.52	E 45.22
L17	Ziyeka 1	N 35.52	E 45.22
L18	Ziyeka 2	N 35.52	E 45.23
L19	Warmizyar 1	N 35.51	E 45.23
L20	Warmizyar 2	N 35.51	E 45.25
L21	Gawani 1	N 35.50	E 45.25
L22	Gawani 2	N 35.50	E 45.25
L23	Gawani 3	N 35.50	E 45.23
L24	Latif Awa	N 35.49	E 45.23

Results and Discussion

The study area was one of the most important agricultural areas in the province, not because it contains huge numbers of greenhouses, but also because it contains vast areas of farms and forests, in addition to inhabited villagers who depend directly for their livelihood on agriculture. So, the present investigation was done in some villages that were randomly chosen as they were infected with nematodes (Upper Warmizyar 1, Lower Warmizyar 2, Mahmudia, Ali Bzaw 2, Penjsharnma, Kani Shaya 1, Kani Shaya 2, Qushqaya, Kani Large, Bagajani 2, Latif Awa and the others that are not infected) are shown in Table 3 (Upper Warmizyar 1, Lower Warmizyar 2, Mahmudia and Ali Bzaw 1).

Table 3: GIS coordinates for villages affected or not with nematodes in Tainal Watershed.

Location	Village name	Latitude	Longitude	Crops	Description
L 1	Warmizyar 1	35.51	45.23	Tomato	affected
L 2	Warmizyar 2	35.51	45.25	Cucumber	affected
L 3	Mahmudia	35.52	45.19	Tomato	affected
L 4	Ali Bzaw 2	35.55	45.17	Cucumber	affected
L 5	Penjsharnma	35.54	45.19	Tomato	affected
L 6	Kani Shaya 1	35.53	45.21	Cucumber	affected
L 7	Kani Shaya 2	35.52	45.20	Cucumber	affected
L 8	Qushqaya	35.55	45.19	Tomato	affected
L 9	Kani Big	35.56	45.17	Cucumber	affected
L 10	Bagajani 2	35.56	45.15	Cucumber	affected
L 11	Latif Awa	35.49	45.23	Cucumber	affected
L 12	Gawani 1	35.50	45.25	Cucumber	non affected
L 13	Gawani 2	35.50	45.25	Cucumber	non affected
L 14	Gawani 3	35.50	45.23	Cucumber	non affected
L 15	Ziyeka 1	35.52	45.22	Cucumber	non affected
L 16	Ziyeka 2	35.51	45.23	Cucumber	non affected
L 17	Halay Sarchawa 1	35.52	45.20	Pepper	non affected
L 18	Halay Sarchawa 2	35.53	45.19	Cucumber	non affected
L 19	Ali Bzaw 1	35.55	45.18	Pepper	non affected
L 20	Shuwankara	35.56	45.19	Cucumber	non affected
L 21	Tui Awlia	35.55	45.19	Tomato	non affected
L 22	Koyik	35.56	45.17	Pepper	non affected
L 23	Mewk	35.57	45.17	Cucumber	non affected
L 24	Bagajani 1	35.57	45.17	Cucumber	non affected

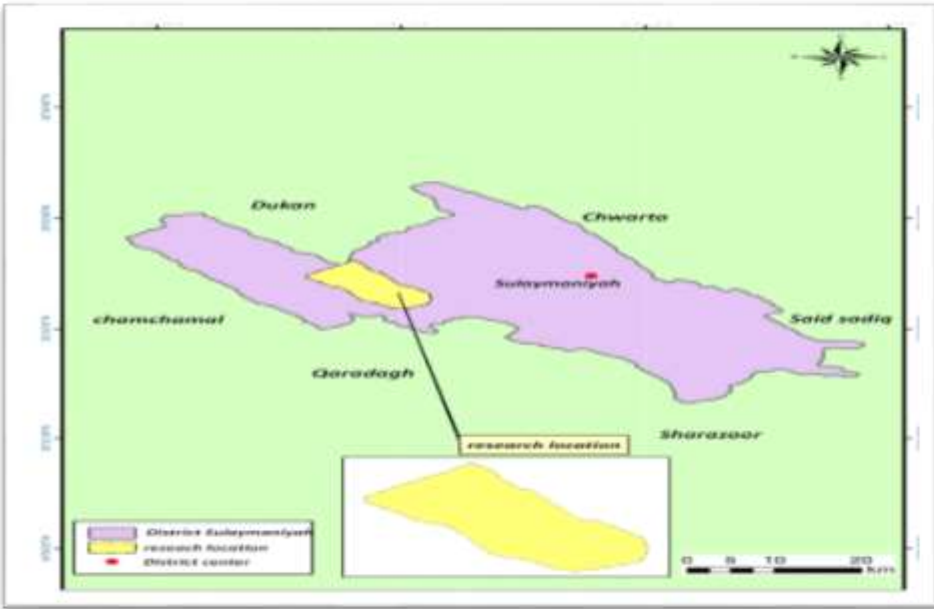

Figure 2: Locations area in Sulaimaniyah Province, north Iraq.

Table 4: Plant analysis for some greenhouses infested and non-infested with nematodes.

Village name	BRIX (%)	Chlorophyll (mg/g)	N (mg)	P (mg)	K (mg)	Ca (mg)	Mg (mg)	Protein (mg)
Mewk	8	28	56.8[a]	19.7[b]	61.3[c]	47.7	10.5	0.47
Bagajani 2	12.6	29.2	22.4[d]	7.85[d]	29.3[d]	23.5	4.7	0.38
Kani Big	7.6	25.35	33.6[c]	22.6[b]	71.6[b]	16.1	8.25	0.45
Shuwankara	11	41	51.4[b]	25.5[a]	141[a]	15	13.15	0.62
Ali Bzaw 1	11.5	41	59.7[b]	19.6[b]	59.9[c]	40.5	9.4	0.57
Ali Bzaw 2	6.1	19.4	20.0[d]	18.4[c]	69.7[b]	9.55	7.2	0.365
Kani Shaya 1 Shaya	8.35	21.44	31.3[c]	25.3[a]	78.6[b]	14.45	7.95	0.65
Halay Sarchawa 1	14	41	57.6[b]	16.9[c]	58.1[c]	44	11.15	0.61
Ziyeka 2	9.5	38	68.2[a]	23.1[a]	69.8[b]	54.5	11.5	0.66
Warmizyar 2	7.8	22.3	37.0 [c]	21.6[b]	91.8[b]	17.15	7.8	0.58
Gawani	10	38.5	60.4[a]	21.6[b]	66.7[b]	48.4	10.75	0.52
Latif Awa	6.9	19.1	30.5[c]	18.9[d]	73.2[b]	14.3	63	0.51

* Means with different letters are significantly different according to Duncan's multiple range tests at $P \leq 0.05$.

** In each greenhouse, 10 plants were selected for plots.

Table 5: Survey in Tainal Watershed, plant and nematodes analysis.

Village name	Fat (g)	Ash (g)	Moisture	Carbohydrates (g)	Larvae	Egg mass	Galls
Mewk	0.11	0.46[b]	77.2[b]	2.05	-	-	-
Bagajani 2	0.095	0.03[d]	91.9[a]	2.15	458[d]	16	20
Kani Big	0.1	0.35[c]	64.5[c]	1.55	515[c]	23	16
Shuwankara	0.12	0.51[a]	89.3[a]	3.4	-	-	-
Qushqaya	+	+	+	-	615[b]	24	38
Ali Bzaw 1	0.12	0.51[a]	73.3[b]	2.2	-	-	-
Ali Bzaw 2	0.09	0.22[d]	82.5[a]	2.3	588[b]	20	30
Penjsharn	+	+	+	-	695[a]	31	36
Kani Shaya 1	+	+	+	-	622[b]	27	36
Kani Shaya 2	0.08	0.32[c]	77.5[b]	2.05	568[c]	30	38
Halay Sarchawa	0.13	0.63[a]	92.6[a]	3.95	-	-	-
Mahmudia	+	+	+	-	706[a]	39	45
Ziyeka 1	0.16	0.51[b]	81.3[b]	2.8	-	-	-
Warmizyar 1	+	+	+	-	487[d]	19	26
Warmizyar 2	0.085	0.38[c]	77.4[b]	2.3	290[e]	13	19
Gawani 3	0.10	0.58[a]	86.5[a]	3.7	-	-	-
Latif Awa	0.075	0.35[c]	65.5[c]	1.35	425[d]	17	21

*Different letters show significant difference according to Duncan's multiple range at $P \leq 0.0$.

** In each greenhouse, 10 plants were selected for plots.

\+ Means no reading as plants were not affected with nematodes, so, they didn’t reach this stage.

\- Means on reading as plants were affected with nematodes.

In soils infected with nematodes, some parameters, such as total nitrogen, available phosphorus and potassium, caused a limeted decrease in the ratios of these parameters (Ruess, 1995). However, their generic richness was decreased, and community structure was altered by increasing the abundance of inhibiting and non-direct effects on the environment were seen (Table 4).

Table 5 showed that soils epidemics with nematodes significantly affect differences negatively on some plant properties directly (fats, ash and moisture) causing many changes like death of young branches and the continuation of death, and nematode occurs in the complexity of the roots so that the absorption of water with the increase of loss of transpiration and evaporation leaves and branches (Li et al., 2010).

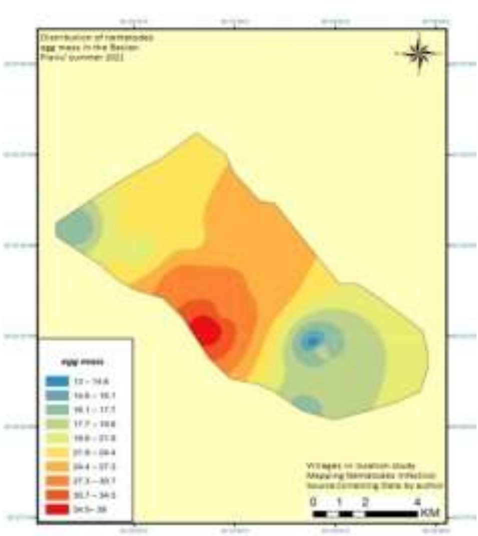

Figure 3: Depending on Table 4. Survey for distribution of egg mass of nematode by ArcGIS 10.1 program.

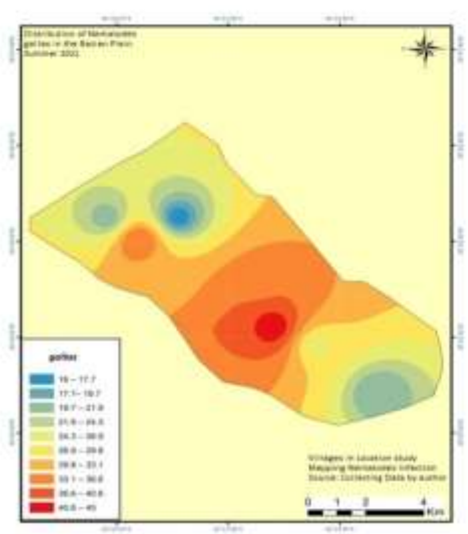

Figure 4: Depending on Table 4. Survey for distribution of galls of nematodes by ArcGIS 10.1 program.

The spread of root-knot nematode larvae in Mahmudia, Kani Penjsharnma and Kani Shaya with populations in 706, 695 and 622/ 250 g soil were the highest in these areas (Figures 3 & 4). After the present investigation in this matter for many years, farmers in this site did not use the scientific or right ways to control or prevent the spread of this nematode. The reason of speared of this nematode is due to use the plow without sterilization for other farms (Goswami & Singh, 2004).

Meloidogyne species were common in vegetable world where they parasitize vascular root tissues and induce their familiar root galls (Abawi & Widmer, 2000; Davies et al., 2003; Anwar & Mckenry 2010). *M. javanica* is the common nematode in this region. Nematode root galling causes obstruction of root systems and its presence is often been associated with increased incidence and severity of *Fusarium* wilts of several field crops (Martin et al., 1994).

In this survey, only *M. javanica* was currently considered to be economically damaging cucumber and tomato. *M. javanica* was the commonly species pest on cucumber in Tainal Watershed. It is likely that the root-knot second-stage juveniles recovered were based as *M. javanica* on the continuous cucumber production (Gebremikael et al., 2016). This indicates that improved frequency of irrigation can alleviate some plant stress in this damaged area. Although nematode populations may be higher in this area, the example illustrates that a different set of factors (soil and management factors) can influence the pattern of nematode incidence and plant damage within a field (Baird et al., 1996).

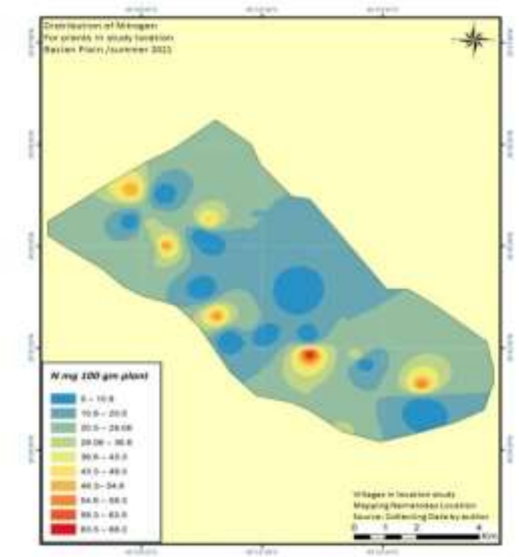

Figure 5: Depending on Table 4. Distribution of nitrogen for plants in study location by ArcGIS 10.1.

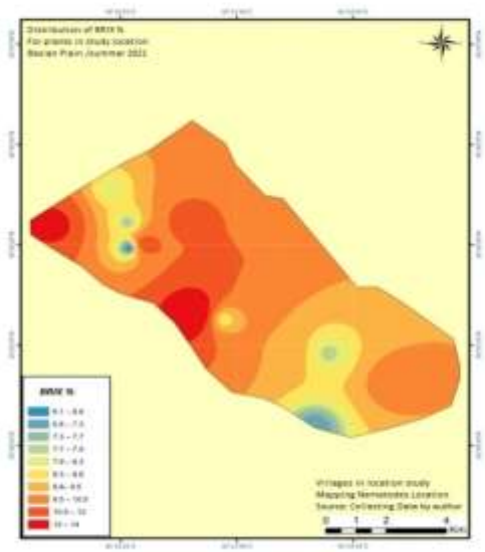

Figure 6: Depending on Table 4. Distribution of BRIX % for plants in study location by ArcGIS 10.1.

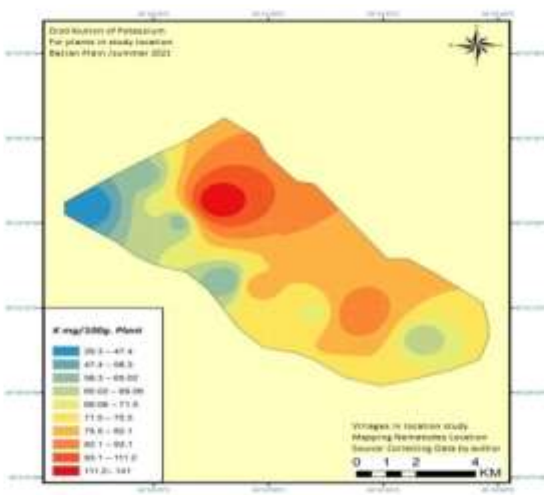

Figure 7: Depending on Table 4. Distribution of Potassium for plants in study location by ArcGIS 10.1.

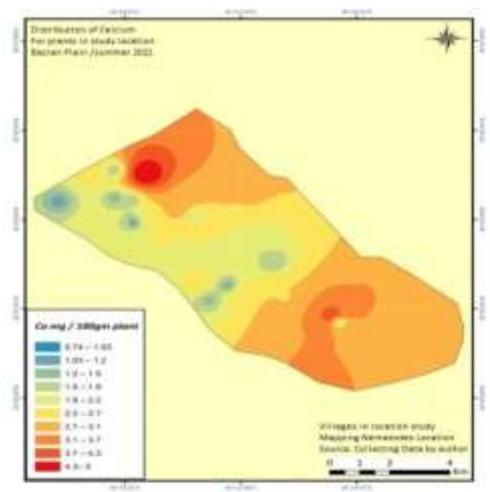

Figure 8: Depending on Table 4. Distribution of calcium for plants in study location by ArcGIS 10.1.

The importance of Ca levels in the cytoplasm have a role as signaling mechanisms for environmental stress. Ca pumps are directed out of the cytoplasm, either to vacuoles, where it may be precipitated as calcium oxalate, or across the plasma, the function of the majority of plant Ca was structural, in the cell walls of shoots and roots so farmers need to know these basics on calcium (Wright & Rowland, 2008).

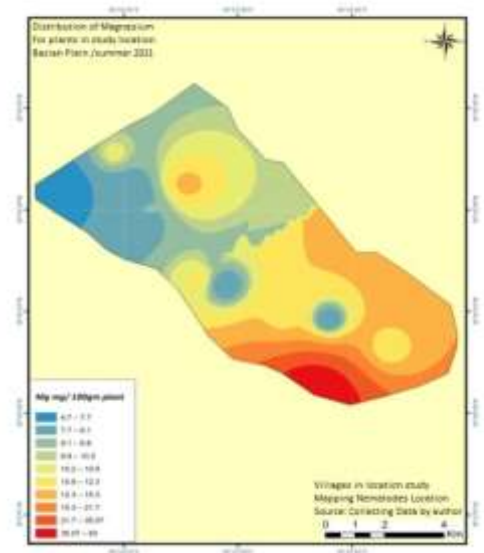

Figure 9: Depending on Table 4. Distribution of magnesium for plants in study location by ArcGIS 10.1.

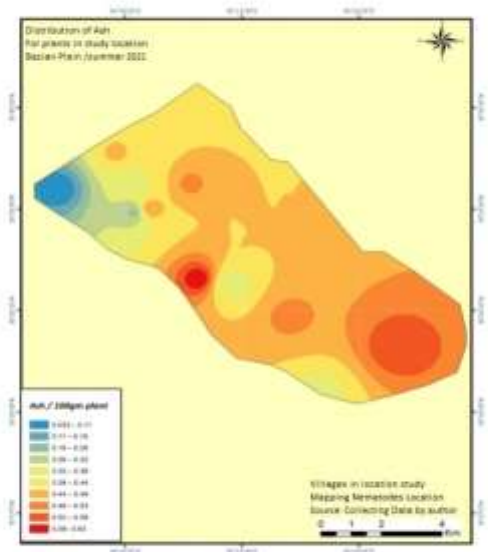

Figure 10: Depending on Table 4. Distribution of ash for plants in study location by ArcGIS 10.1.

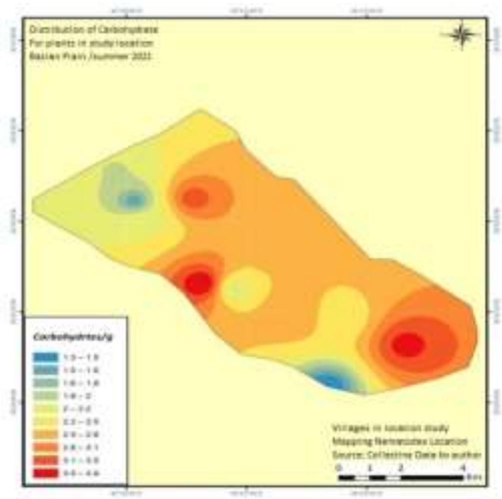

Figure 11: Depending on Table 4. Distribution of carbohydrates for plants in study location by ArcGIS 10.1.

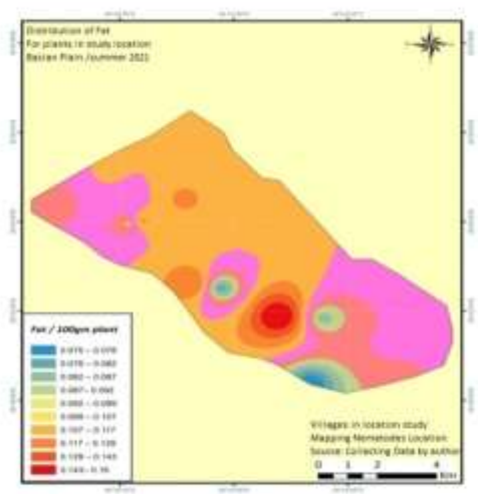

Figure 12: Depending on Table 4. Distribution of fat for plants in study location by ArcGIS 10.1.

Plant ratio of magnesium was higher (13.15) in Shuwankara and Ziyeka (11.5) as in Figure 9. So, these were very low ratios as compared with those of Oliveira et al. (2010). As with the nutrient problems, plant parasitic nematodes affecting on the vegetables will make a series of problems facing the farmers, therefore, they help to pass this (Hue et al., 2005).

Chloride (Cl) is the most recent addition to the list of essential elements. Although chloride was classified as a micronutrient, leaf chlorophyll is a direct indicator of nitrogen status and growth rate of the plant (Table 4). The highest amount of chlorophyll in collected samples was 41 mg/g in Ali Bzaw, Shuwankara and Sarchawa. This agrees with nitrogen ratio in some plants (Liu et al., 2007). In order to limit oxidative damage under stress, plants have developed a series of detoxification systems that break down the highly toxic reactive oxygen species, catalyses and peroxidases. Peroxidase comprises one important class of pathogenesis related proteins implicated in "defense responses" in which an important role is to catalyze the formation of phenolic radicals at the expense of H_2O_2 (Gaspar et al., 1991).

Phenolic compounds in plants played a vital role in their defense system, particularly redox response and free radical scavenging. Furthermore, accumulation of phenols at the site of infection was characteristic in plant defense response, caused rapid cell death and prevents penetration of pathogens (Isah, 2019). Increase in phenolic compounds due to nematode infection had been reported in several studies (Nagesh & Reddy, 2004; Liu et al., 2007). Chlorophyll is an important bimolecular which led to photosynthesis and allows plants to absorb energy from light (Mandal & Dutta, 2020). Nematode infection reduces chlorophyll content and ultimately the carbohydrate supply to the nodule resulting lower nitrogen fixation (Figure 11). The ratio of ash (Table 5) is low, as the highest ratio were in Sarchawa and Gawani (0.63 and 0.58 g, respectively) and these are lower than 1% as reported by Füzesi et al. (2015).

The ratio of BRIX (Table 4) in villages of Bagajani and Ali Bzaw 1 (12.6% and 11.5%, respectively) were the highest. From Figure 5, plants in each villages (Halay Sarchawa 3.95 g, Gawani 3.7 g and Shuwankara 3.4 g) have the highest weight of carbohydrates that return to plants produce a high diversity of natural products with a prominent function in the protection against predators and pathogens (Jones, 1976). These mechanisms include pre-existing physical and chemical barriers, as well as inducible defense response in the form of induction of defense-related enzymes that become activated upon pathogens. In parasitic nematodes, they are particularly crucial for digestion of host tissues and evasion of host immune responses (Thakur et al., 2014). Pathogen infection and various abiotic stresses lead to overproduction of reactive oxygen species such as superoxide anion, singlet oxygen and hydrogen peroxide which are produced continuously as byproducts of various metabolic pathways, and are highly reactive and toxic. They produce oxidative stress by damaging proteins, lipids and carbohydrates (Sreedhar et al., 2013). Halay Sarchawa, Bagajani 2 and Shuwankara had the highest moisture levels (92.6%, 91.9% and 89.3%, respectively) according to Table 5. In comparison with the cucumber's usual water content of 96%, these moderate ratios are quite low (Guelinckx et al., 2016).

In conclusion, farmers are using chemical nematicides which temporarily effect most nematicides, but nematode populations are never completely eliminated with a single nematicide application. Since nematode eggs are resistant to nematicides treatments, it is important that nematicides be applied after egg hatching.

Acknowledgements

Special thanks for Dr. Nasreen Mohi-aldin from Sulaimaniyah University for helping in revising this manuscript. I would like to thank the Nematology Lab. at Sulaimaniyah Research Directorate for their assistance in data collection.

References

Abawi, G.S. & Widmer, T.L. (2000). Impact of soil health management practices on soilborne pathogens, nematodes and root diseases of vegetable crops. Appl. Soil Ecol., 15(1): 37-47. DOI:10.1016/S0929-1393(00)00070-6.

Anwar, S.A. & Mckenry, M. (2010). Incidence and reproduction of *Meloidogyne incognita* on vegetable crop genotypes. Pakistan J. Zool., 4(2): 135-141.

Baird, R.E.; Davis, R.F.; Alt, P.J.; Mullinix, B.G. & Padgett, G.B. (1996). Frequency and geographical distribution of plant-parasitic nematodes on cotton in Georgia. J. Nematol., 28(4S): 661-667. PMC2619744.

Davies, K.G.; Warry, A.; Waterman, J.; Bird, D.M. & Opperman, C.H. (2003). Functional genomics of *Pasteuria penetrans*: A bacterial parasite of plant parasitic nematodes. Recent poster from Homepage of Davies, K.G. www.rothamstead.ac.uk/ppi/staff/kgd.html.

Dhaliwal, G.S. & Koul, O. (2007). Biopesticides and pest management: Conventional and biotechnological approaches. Kalyani Publ., New Delhi: 455 pp.

El-Sherif, A.G.; Refaei, A.R.; El-Nagar, M.E. & Salem, H.M.M. (2007). Integrated management of *Meloidogyne incognita* infecting eggplant by certain organic amendments, *Bacillus thuringiensis* and oxamyl with reference to N P K and total chlorophyll status, Plant Pathol. J., 6(2): 147-152. DOI:10.3923/ppj.2007.147.152.

Freckman, D.W. & Caswell, E.P. (1985). The ecology of nematodes in agroecosystems. Ann. Rev. Physiopathol., 23: 275-296.

Füzesi, I.; Heil, B. & Kovács, G. (2015). Effects of wood ash on the chemical properties of soil and crop vitality in small plot experiments. Acta Silv. Lign. Hung., 11(1): 55-64. DOI:10.1515/aslh-2015-0004.

Gaspar, T.; Penel, C.L.; Hagage, D. & Grappin, H. (1991). Peroxidases in plant growth, differentiation and developmental processes. In: Grappin, H.; Penel, C.L. & Aspar. T.G. (eds.). Biochemical, molecular and physiological aspects of plant peroxidases. Univ. de Geneva Press: 249-280.

Gebremikael, M.T.; Steel, H.; Buchan, D.; Bert, W. & De Neve, S. (2016). Nematodes enhance plant growth and nutrient uptake under C and N-rich conditions. Sci. Rep., 6: 32862. DOI:10.1038/srep32862.

Gill, H.K. & McSorley, R. (2011). Cover crops for managing root-knot nematodes. Univ. Florida, IFAS Extension, ENY063: 6 pp.

Giné, M.; López-Gómez, M.; Vela, M.D.; Ornat, C.; Talavera, M.; Verdejo- Lucas, S. & Sorribas, F.J. (2014). Thermal requirements and population dynamics of root-knot nematodes on cucumber and yield losses under protected cultivation. Plant Pathol., 63: 1446-1453. DOI:10.1111/ppa.12217.

Goswami, B.K. & Singh, S. (2004). Fungal bioagents for the management of root-knot nematode in tomato. Pestic. Res. J., 16(1): 9-12.

Guelinckx, I.; Tavoularis, G.; König, J.; Morin, C.; Gharbi, H. & Gandy, J. (2016). Contribution of water from food and fluids to total water intake: Analysis of a French and UK population surveys. Nutrients, 8: 630, 11 pp. DOI:10.3390/ nu8100630.

Hue, N.V.; Serracin, M.; Schmitt, D.P. & Bittenbender, H.C. (2005). Nutrient and nematode status of coffee and soils from orchards in Hawaii. Commun. Soil Sci. Plant Anal., 35(13-14): 2023-2036. DOI:10.1081/LCSS-200026831.

Isah, T. (2019). Stress and defense responses in plant secondary metabolites production. Biol. Res., 52, Santiago. DOI:10.1186/s40659-019-0246-3.

Jones, F.G.W. (1976). Pests, resistance and fertilizers. In: Proceedings of the 12th Colloquium of the International Potash Institute on Fertilizer Use and Plant Health. Worblaufen, Bern, Switzerland: 233-258.

Jones, J.T.; Haegemen, A.; Danchin, E.G.J.; Gaur, H.S.; Helder, J.; Jones, M.G.K.; Kikuchi, T.; Manzanilla-López, R.; Palomares-Rius, J.E.; Wesemael, W.M.L. & Perry, R.N. (2013). Top 10 plant-parasitic nematodes in molecular plant pathology. Mol. Plant Pathol., 14(9): 946-961. DOI:10.1111/mpp.12057.

Karajeh, M. (2008). Interaction of root-knot nematode (*Meloidogyne javanica*) and tomato as affected by hydrogen peroxide. J. Plant Prot. Res. 48(2): 181-187. DOI:10.2478/v10045-008-0021-x.

Kiewnick, S. & Sikora, R.A. (2006). Biological control of the root-knot nematode *Meloidogyne incognita* by *Paecilomyces lilacinus* Strain 251. Biol. Control J., 38(2): 179-187. DOI:10.1016/j.biocontrol.2005.12.006.

Li, Q.; Jiang, Y.; Liang, W.; Lou, Y.; Zhang, E. & Liang, C. (2010). Long-term effect of fertility management on the soil nematode community in vegetable production under greenhouse conditions, Appl. Soil Ecol., 46(1): 111-118. DOI:10.1016/j.apsoi l.2010.06.016.

Liu, Y.; Ren, D.; Pike, S.; Pallardy, S.; Gassmann, W. & Zhang, S. (2007). Chloroplast-generated reactive oxygen species are involved in hypersensitive response-like cell death mediated by a mitogen-activated protein kinase cascade. Plant J., 51(6): 941-954. DOI:10.1111/j.1365-313X.2007.03191.x.

Mandal, R. & Dutta, G. (2020). From photosynthesis to bio sensing: Chlorophyll proves to be a versatile molecule. Sensors Int., 1: 100058; 7 pp. DOI:10.1016/ j.sintl.2020.100058.

Mankau, R. (1980). Biological control of nematode pests by natural enemies. Ann. Rev. Phytopathol., 18: 415-440. DOI:10.1146/annurev.py.18.090180.002215.

Martin, S.B.; Mueller, J.D.; Saunders, J.A. & Jones, W.I. (1994). A survey of South Carolina cotton fields for plant-parasitic nematodes. Plant Dis., 78: 717-719.

Moon, H.-S.; Khan, Z.; Kim, S.-G.; Son, S.-H. & Kim, Y.-H. (2010). Biological and structural mechanisms of disease development and resistance in chili pepper infected with the root-knot nematode. Plant Pathol. J., 26(2): 149-153.

Nagesh, M. & Reddy, P.P. (2004). Biochemical changes in *GIomus fasciculatum* colonized roots of *Lycopersicon esculentum* in presence of *Meloidogyne incognita*. Indian J. Exp. Biol., 42: 721-728.

Oliveira, L.M.; Paivo, R.; Santana, J.R.F.; Periera, F.D.; Nogueira, R.C. & Silva, L.C. (2010). Effects of cytokinins on in vitro mineral accumulation and bud development in *Annona glabra* L. Ciênc. Agrotec., 34(6): 509-524. DOI:10.1590/S1413-70542010000600012. (In Portuguese).

Ruess, L. (1995). Studies on the nematode fauna of an acid forest soil: Spatial distribution and extraction. Nematology, 41: 229-239.

Seif-Ennasr, M.; Bouchaou, L.; El Morjani, Z.E.; Hirich, A.; Beraaouz, E. & Choukr-Allah, R. (2020). GIS-based land suitability and crop vulnerability assessment under climate change in Chtouka Ait Baha, Morocco. Atmosphere, 11(11): 1167. DOI:10.3390/atmos11111167.

Sharon, E.; Bar-Eyal, M.; Chet, I.; Herrera-Estrella, A.; Kleifeld, O. & Spiegel, Y. (2007). Biological control of the root-knot nematode *Meloidogyne javanica* by *Trichoderma harzianum*. Phytopathology, 91(7): 687-693. DOI:10.1094/PHYTO.2001.91.7.687.

Sreedhar, M.; Chaturvedi, A.; Aparna, M.; Kumar, P.D.; Singhal, R.K. & Venu-Babu, P. (2013). Influence of γ- radiation stress on scavenging enzyme activity and cell ultrastructure in groundnut (*Arachis hypogaea* L.). Adv. Appl. Sci. Res., 4(2): 35-44.

Thakur, P.K.; Kumar, M.; Kumar, J.; Gantasala, N.P. & Rao, U. (2014). Structural and functional analysis of cathepsin S of *Heterodera* spp.: A promising candidate for its control. Indian J. Exp. Biol., 52(3): 223-231. PMID:24669665.

Wright, D.J. & Rowland, A.J. (2008). Susceptibility of different developmental stages of the root-knot nematode, *Meloidogyne incognita*, to the nematicide oxamyl. Ann. Appl. Biol., 100(3): 521-525. DOI:10.1111/j.1744-7348.1982.tb01418.x.

Zuckerman, M.; DePaulo, B.M. & Rosenthal, R. (1981). Verbal and nonverbal communication of deception. Adv. Exp. Soc. Psychol., 14: 1-59. DOI:10.1016/s0065-2601(08)60369-x.