OPEN ACCESS Pakistan Journal of Agricultural Research

Research Article

Soil Inhabiting Mite Diversity (Acari) of Mango Orchards from Dera Ghazi Khan, Pakistan

Bilal Saeed Khan[1]*, Muhammad Arslan[1], Abdul Ghaffar[2], Muhammad Farooq[2], Saghir Ahmad[3], Sami Ullah[4] and Awais Rasool[5]

[1]Department of Entomology, University of Agriculture, Faisalabad, Pakistan; [2]Entomological Research Institute, Ayub Agricultural Research Institute (AARI), Faisalabad, Pakistan; [3]Cotton Research Institute, Multan, Pakistan; [4]College of Agriculture, University of Sargodha, Sargodha, Pakistan; [5]PSO, Institute of Plant and Environment Protection, NARC, Islamabad, Pakistan.

Abstract | Soil mites are considered as edaphic living organisms because these are responsible in maintaining the soil fertility through their decomposition and nutrient renewal activities. perimental statistics was applied to estimate the variety of soil mite diversity, seasonal variation and influence of intercropping within mango orchards through diversity index. A total of 1898 soil inhabiting mite sample slides were prepared from soil collected samples and after microscopic observation of slide specimen, 08 different families were recognized as Laelapidae, Pachylaelapidae, Ameroseiidae, Macrochelidae, Parasitidae, Phytoseiidae, Uropodidae, and Bdellidae. Macrochelidae and Parasitidae were the most prevalent families while Pachylaelapidae and Bdellidae were recorded in the lowest numbers. The abundance of soil-inhabiting mites with respect to different locations in various months revealed that maximum abundance of mite families were recorded from Kotla Gurmani (38.5) followed by Kot Chutta (37.0) during October and minimum abundance was recorded during September from Mana Ahmadani (14.8). The maximum richness was recorded from mango orchards during September from Basti Hala (S=6.58) whereas richness remained statistically at par during October and February. The pearson correlation analysis demonstrated that most mite families had a negative correlation with morning and evening relative humidity while the positive correlation with maximum and minimum temperature. The results showed higher Shannon diversity index was observed in Mana Ahmadani during October and February (2.04 and 2.03, respectively) whereas the least value was observed in Basti Halla during February (1.60). Finally it could be concluded that farmers should consider conservation activities of mite fauna through intercropping to enhance the soil fertility thereby fruit production.

Received | September 01, 2021; **Accepted** | August 15, 2022; **Published** | September 06, 2022
***Correspondence** | Bilal Saeed Khan, Department of Entomology, University of Agriculture, Faisalabad, Pakistan; **Email:** bilalentomologyuaf@gmail.com
Citation | Khan, B.S., M. Arslan, A. Ghaffar, M. Farooq, S. Ahmad, S. Ullah and A. Rasool. 2022. Soil inhabiting mite diversity (Acari) of mango orchards from Dera Ghazi Khan, Pakistan. *Pakistan Journal of Agricultural Research,* 35(3): 490-498.
DOI | https://dx.doi.org/10.17582/journal.pjar/2022/35.3.490.498
Keywords | Mango orchards, Mite diversity, Mesostigmata, Conservation, Pakistan

Introduction

Mango *Mangifera indica* L. (Anacardiaceae: Sapindales) is a prime fruit and has great economic importance for Pakistan. Invertebrate and vertebrate organisms also contribute a lot to various soil processes. Among invertebrates, arachnid fauna constitutes almost 45-50% of total arthropod diversity of soil. Mites belong to a well-known category of arthropod diversity due to variability and richness within soil. Mites participate in different soil operations and also act as predators against different insect pests (Yahya *et al*., 2020). Various agricultural practices and seasonal changes have secured influence on soil organisms. Soil organisms consists of many arthropods species, 23 % of those are invertebrates, among which 85% of soil fauna comprises hexapods (Culliney, 2013).

Arachnids (mites) are the most famous and diverse group of Arthropods that also play a significant role in maintaining the physico-chemical dynamics in soil (Haq, 2007). Fluctuations in the population density and diversity of mites up to the depth of 10 cm of soil have been reported over period of 12 months (Sharma and Parwez, 2017). Earlier, studies reported the inventory of soil mites from citrus orchards from northern Tunisia, Mornag and Bizerte. The soil fauna was predominantly composed of Oribatida followed by Mesostigmata families. The most frequent and abundant Oribatida families were Phenopelopidae and Oribatulidae, while Laelapidae and Parasitidae and Pachylaelapidae were the predominant families of Mesostigmata (Belaam-Kort *et al*., 2018). Aerial mite pests of mango, include mango mud mites *Eriophyes mangiferae* (Sayed), red mites, *Aceria mangifera* (Sayed), spider mite, *Oligonychus mangiferus* (Rahman and Sapra), broad mite, *Polyphagotarsonemus latus* (Banks) and erinose mite, *Aceria litchi* (Keifer). These mites usually injured the surface of leaves and extract leaf juice for feeding (Sarwar, 2015). Orchards soil fauna heavily composed of species of the soil Arachnids like Mesostigmata, Prostigmata and Oribatida. They are abundantly found in slightly wet to saturated soils, vegetated margins of large and small wetlands and mosses in streams (Lindquist, 2003; Krantz and Walter, 2009). Soil process of the population fluctuation of soil micro fauna is very difficult to explain without collaboration of abiotic factors (Miyazawa *et al*., 2002). Most of the mite populations are sensitive to change in soil composition and hence proved to be good predictors of soil condition. Agriclutral soils are found to be the most abundant in terms of soil inhabiting mites followed by orchard and natural land-use soils (Yahya *et al*., 2020). While very little scientific information is vailable on diversity of soil inhabiting arachnids of mango orchards in Pakistan. This research work was planned to estimate the diversity, richness, abundance and the effect of abiotic factors on soil mite population in mango orchards. Also, the soil mite population was evalauated in relation to different intercropping patterns of orchards.

Materials and Methods

Survey and collection of samples

Four mango growing areas of Dera Ghazi Khan, Punjab, Pakistan viz., Kotla Gurmani (A1) (29.77° N, 70.61° E), Kot Chutta (A2) (29°53 N, 70°39 E), Mana Ahmadani (A3) (29°47′ N, 70°35 E) and Basti Halla (A4) (29°46 N, 70°36 E) (Figure 1) were selected for assessing the abundance and richness of soil inhabiting mites during 2019-20. In each area, four orchards were selected, one intercropped with cotton (*Gossypium* spp.) (O1), one with barseem (*Trifolium alexandrinum*) (O2) and two without any intercropping (O3 and O4). Soil samples were collected during three months October-19, November-19 and February-20 from each identified area. Collection of samples was done by a hand-made tool i.e., steel core measuring one litter capacity having 10.5 cm diameter and 12 cm length, with detachable steel rod of 45 cm to draw the sample from soil beneath the canopy of mango trees. Four samples (500 g) of each tree side were taken from NEWS (North, East, West and South). The same procedure was replicated for at least four times.

Extraction of mites from soil samples

Samples were transferred to plastic jars to avoid the escape of mites and moisture contents from soil samples. The collected samples were properly tagged and brought to Acarology Research Laboratory, University of Agriculture, Faisalabad. The modified Berlese Tullgren funnels apparatus was used to isolate the soil mites from collected samples. The soil samples were processed for 48 hours to ensure maximum extraction. The specimens were preserved within mini vials having 75-80% ethyl alcohol and few drops of glycerin. Vials were tagged according to date of collection and locality for further studies.

Links Researchers

Figure 1: *Location mark in the Map shows the localities of orchards in D. G. Khan from where samples were collected.*

Examination and identification of mounted specimens

Soil mites were separated from other soil arthropods with the help of microscope and Hoyer's Medium was used to make permanent mounts. The mounted specimens were studied under phase-contrast microscope (Meiji Techno MT4210H) and identified up to family level by using taxonomic keys of Krantz and Walter (2009) and Evans and Till (1979).

Statistical analysis

The diversity measurement of soil arachnids in mango orchards was constructed by applying diversity index (Shannon, 1948) to evaluate diversity, richness and abundance.

$$H = -\sum[(p_i) \times \log p_i)] \quad \ldots (1)$$

Where,

H= Shannon diversity index; Pi=ith proportion of each family of mites from each analyzed sample. It also indicates the relative abundance of each family for this study.

The diversity indices, individual-based plots were calculated by using computer software 'PAST' (Hammer *et al.*, 2001). The data on different parameters were analyzed by using ANOVA and separated by Tukey's HSD post-hoc test at 5% level of significance. The pearson correlation analysis was performed to evaluate the relationship between weather factors (weather data from Department of Plant Protection, DG Khan) and soil mite abundance. This analysis was performed using R-studio (v. 1.1.453) with a significance level of α=0.05.

Results and Discussion

Community structure (%age) of mite families

A total number of 8 families were noted like Laelapidae, Pachylaelapidae, Ameroseiidae, Macrochelidae, Parasitidae, Phytoseiidae, Uropodidae, Bdellidae from collected specimens of all four orchards. The community structure of soil inhabiting mites was recorded and their total number of specimens belonging to each family with respective percentages are given in Figure 2. The highest number of mites of the family Macrochelidae and Parasitidae was observed and their number was 249 (13.10%) each. Uropodidae was ranked at 2nd position with 239 (12.60%) number of recorded mites. The number of families Laelapidae, Phytoseiidae and Ameroseiidae were 209 (11.00%), 191 (10.10%) and 164 (8.64%), respectively. Pachylaelapidae and Bdellidae families were found with minimum numbers 36 (1.90%) and 86 (4.53%), respectively of specimens.

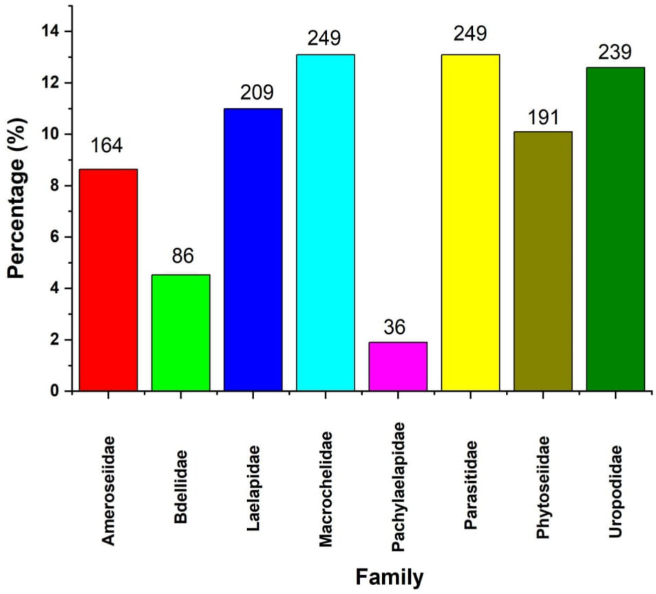

Figure 2: *Number (%age) of various mite families from different orchards, Dera Ghazi Khan. The error bars represent standard errors of mean values.*

Maximum abundance of mite families were recorded from Kotla Gurmani (38.5) followed by Kot Chutta (37.0) during October and minimum was recorded during September from Mana Ahmadani (14.8) (Figure 3). Concerning mite abundance in different orchards, the highest peak was recorded in orchard-4 (O4) from Kotla Gurmani (39.7) and lowest peak regarding abundance was observed in orchard-1 (O1) from Basti Halla (13.8) (Figure 4). The abundance of mite families with respect to different months depicted that the highest peak was observed during October and February in Orchard-4 (O4) whereas the lowest peak was recorded during September in Orchard-1 (O1) (Figure 5).

the maximum richness was observed in orchard-1 (S=6.03) followed by orchard-3 of Basti Halla whereas the lowest peak was observed in orchard-1 (O1) and orchard-4 (O4) of Kotla Gurmani (S=3.17).

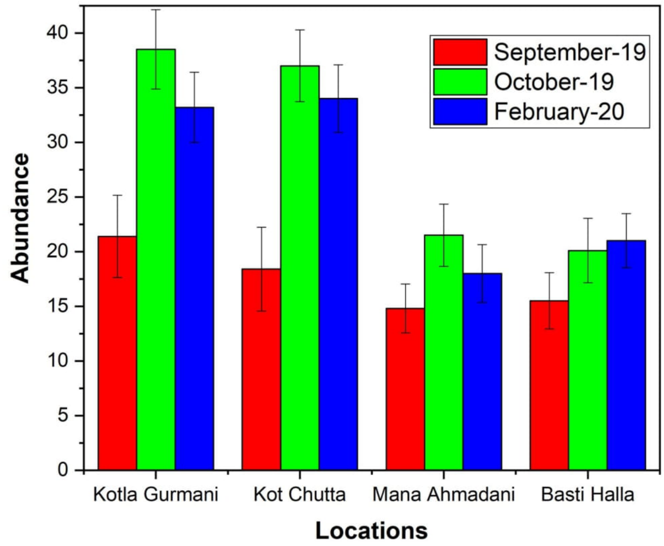

Figure 3: *Abundance of mite families in different months with respect to different locations. The error bars represent standard errors of mean values.*

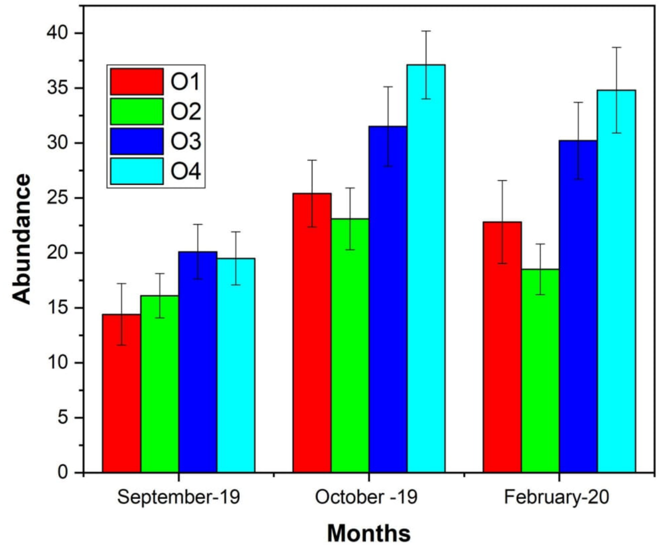

Figure 5: *Abundance of mite families in different orchards with respect to months. The error bars represent standard errors of mean values.*

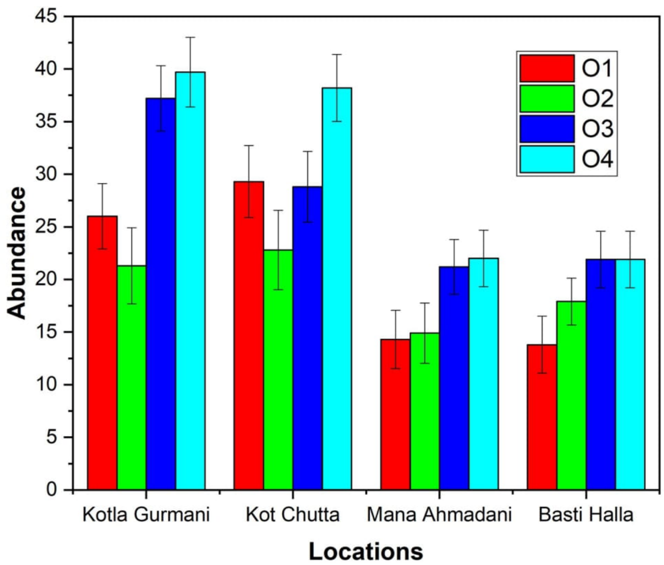

Figure 4: *Abundance of mite families in different locations with respect to orchards types. The error bars represent standard errors of mean values.*

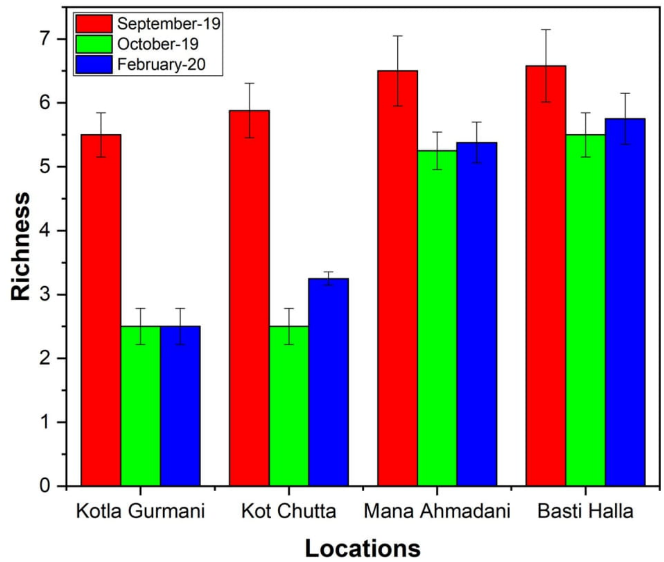

Figure 6: *Richness of mite families in different locations with respect to months. The error bars represent standard errors of mean values.*

Richness of mite families concerning various interactions

The richness of soil-inhabiting mites varied in different months. The maximum richness was recorded from mango orchards during September with S=6.58 from Basti Hala whereas richness remained statistically at par during October and February (Figure 6). Similarly, Figure 7 demonstrated the richness status concerning different orchards. It is evident from the results that

Intercropping effect on the abundance of mite families

The statistical results regarding the abundance of mites after intercropping revealed that the maximum abundance of 30.3 % was observed in orchard-4 (O4) followed by orchard-3 (O3) whereas the least abundance (20.7 %) was observed in orchard-1 (O1) (Figure 8). Concerning mite abundance as a result of intercropping in various locations, Basti Halla had maximum abundance (27.1 %) of mites whereas Kot Chutta recorded least abundance of soil inhabiting mites (22.1 %) (Figure 9).

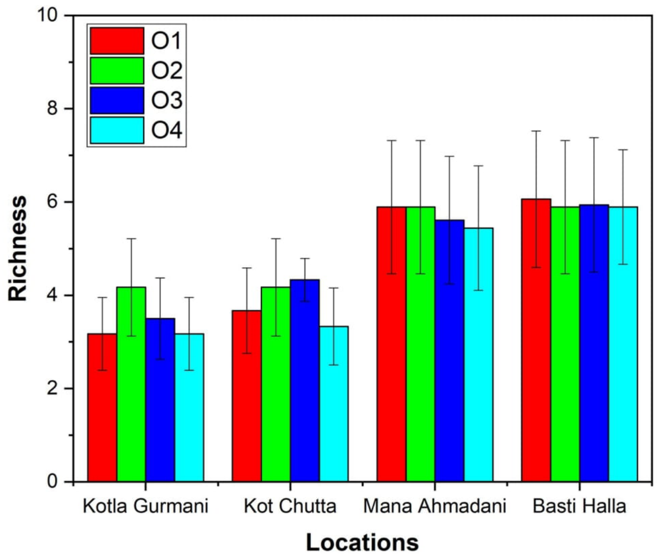

Figure 7: *Richness of mite families in different locations with respect to orchards type. The error bars represent standard errors of mean values.*

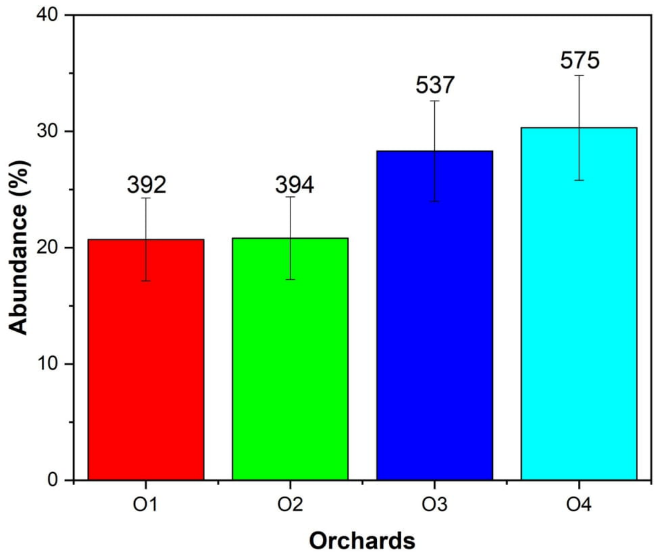

Figure 8: *Intercropping effect on abundance of mite families in different orchard type. The error bars represent standard errors of mean values.*

Pearson correlation of abiotic factors with abundance of soil inhibiting mite families of mango orchards from Dera Ghazi Khan

Pearson correlation analysis of different families of soil-inhabiting mites of mango orchards of different areas of DGK with abiotic factors showed that family Ameroseiidae having a negative correlation with morning and evening relative humidity with coefficient values -0.32 and -0.38, respectively, while the positive correlation with maximum and minimum temperature with correlation coefficient values 0.17 and 0.24. Laelapidae, Phytoseiidae and Bdellidae shared similar relationship as of Ameroseiidae (Table 1). Macrochelidae having a positive correlation with minimum and maximum temperature with correlation coefficient values 0.08 and 0.12, respectively, while it is negatively correlated with morning relative humidity with correlation coefficient -0.03 and positive correlation with evening humidity with correlation value 0.05. Only family Parasitidae having a negative correlation with maximum and minimum temperature range with correlation coefficient values -0.18 and -0.21, respectively, while positively correlates with morning and evening relative humidity with correlation coefficient values 0.23 and 0.24 accordingly. Uropodidae having a negative correlation with maximum temperature, morning and evening relative humidity with correlation coefficient values -0.02, -0.08 and -0.15, respectively, while positively correlates with minimum temperature with correlation coefficient value 0.05 (Table 1).

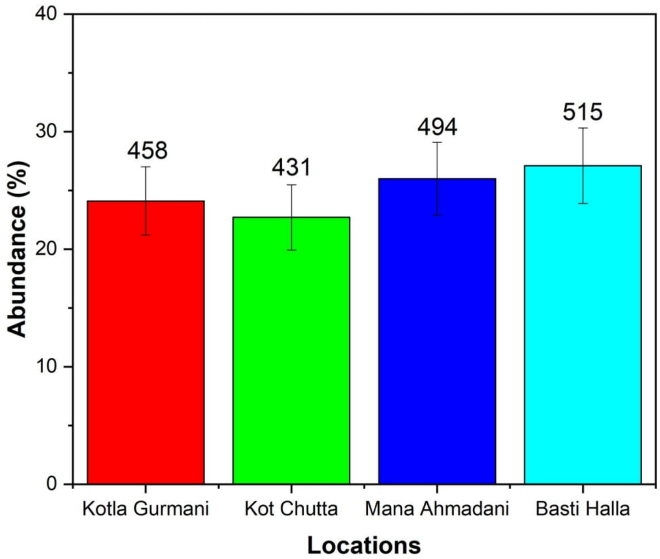

Figure 9: *Intercropping effect on abundance of mite families in different locations. The error bars represent standard errors of mean values.*

Diversity of soil-inhabiting mites

The results of areas with comparison to months, Shannon diversity index of soil inhibiting mites are reported in Table 2. The results showed higher Shannon diversity index was observed from Mana Ahmadani during October and February (2.04 and 2.03, respectively) whereas the least value was observed in Basti Halla (1.60) during February. The highest value of Simpson's index was demostarted during October in Mana Ahmadani (0.86). Fisher's alpha diversity of soil mites from mango orchard areas within different months, showed that there are similar alpha diversity values from different areas within different months. The maximum evenness was recorded from Basti Ahmadani (0.98) during October while least was observed from Basti Halla during February (Table 2).

Table 1: *Overall correlation of abiotic factors with abundance of soil inhibiting mites of mango orchards of Dera Ghazi Khan.*

Mite family	Max. temp (°C)	Min. temp (°C)	Humidity morning (%)	Humidity evening (%)
Ameroseiidae	0.17	0.24	-0.32	-0.38
Laelapidae	0.08	0.08	-0.08	-0.07
Macrochelidae	0.12	0.08	-0.03	0.05
Parasitidae	-0.18	-0.21	0.23	0.24
Phytoseiidae	0.26	0.31	-0.35	-0.36
Uropodidae	-0.02	0.03	-0.08	-0.15
Bdellidae	0.17	0.16	-0.14	-0.10
Pachylaelapidae	0.18	0.12	-0.05	0.06

Note: The correlation coefficient was found to be non-significant for all mite families ($p \leq 0.05$).

Orchard ecosystems are comparatively stable habitats comprised of many arthropod species as compared to normal crops. This is due to less human disturbance and intervention in orchards ecosystem, also providing favorable environment and spaciotemporal distribution of many species of soil arthropods. Availability of such resources enable some species to get their food from different channels within the food web that ultimately increase the survival chances of these soil arthropods (Cohen *et al*., 2012). The current studies evalatuated the soil-inhabiting mites from four orchards of different locations of Dera Ghazi Khan region. The studies confirmed 8 soil-dwelling families such as Laelapidae, Pachylaelapidae, Ameroseiidae, Macrochelidae, Parasitidae, Phytoseiidae, Uropodidae, and Bdellidae with Macrochelidae and Parasitidae being the most abundant families. Another study by Belaam-Kort *et al*. (2018) identified a total of 31 species of mites belonging to 20 families. The acari fauna was predominantly composed of Oribatida followed by Mesostigmata mites. The most frequent and abundant Oribatida families were Oribatulidae and Phenopelopidae, while Parasitidae, Laelapidae and Pachylaelapidae were the predominant families of Mesostigmata.

Intercropping fruit orchards with different crops such as berseem, cotton and clover. enhances the community structure of soil-inhahbitng mites adding fertility to the soil. Our results depicted that in the mango orchards (intercropped with berseem and cotton or without intercropping) of different areas, less diversity of soil-mites was found. The low diversity, richness and abundance of soil inhibiting mites was due to poor soil fertility, less organic matter, low forest area and environmental condition. These results contradicted with the other finding such as Sirrine *et al*. (2008) who reported that intercropping act as ground cover and increase the soil arthropod community diversity richness and abundance.

Table 2: *Comparison of Shannon diversity index of various localities for different months during.*

Month	Location	H-index	Simp. Index	Inv. Simpson index	Unbias Simp. index	Fisher's Alpha	Evenness
February	Kotla Gurmani	1.88	0.84	6.08	0.84	1.57	0.96
	Kotla Chutta	1.73	0.80	5.13	0.81	1.56	0.89
	Mana Ahmadani	2.03	0.86	7.21	0.87	1.83	0.97
	Basti Halla	1.60	0.73	3.64	0.73	1.48	0.82
October	Kotla Gurmani	1.87	0.83	6.04	0.84	1.51	0.96
	Kotla Chutta	1.91	0.85	6.48	0.85	1.53	0.98
	Mana Ahmadani	2.04	0.86	7.39	0.87	1.74	0.98
	Basti Halla	1.89	0.84	6.25	0.84	1.49	0.98
September	Kotla Gurmani	1.91	0.84	6.40	0.85	1.47	0.98
	Kotla Chutta	1.85	0.83	5.89	0.84	1.53	0.95
	Mana Ahmadani	1.99	0.85	6.66	0.86	1.72	0.96
	Basti Halla	2.01	0.85	6.82	0.86	1.70	0.96

Likewise, the studies of intercropping with white clover in peach orchards were studied by Carlsen and Fomsgaard (2008) described that diversity of arthropods and natural enemies enhanced due to intercropping. The higher abundance of soil mites was reported in intercropped citrus orchards compared to non-intercropped orchards (Yahya *et al*., 2020)

Concerning the diversity of soil inhabiting mites based on Shannon diversity index value, no significant difference in all four areas of mango orchards was observed during different months. However, higher Shannon diversity index value 2.0 was observed from Mana Ahmadani and Basti Halla during February, October and September. These results are in agreement with the findings that maximum diversity was found during September (Urhan *et al*., 2008). Many studies revealed that maximum population of soil inhabiting mites was observed in winter and spring season and population of soil mites got reduced during summer season (Begum *et al*., 2014). Similarly, abundance and diversity of soil mites varied during different months was reported by many researchers (Hendrix and Edwards, 2004; Khan *et al*., 2017). Process of population variation of soil mites was observed to be very complicated and not so simple to explain without involvement of abiotic factors (Miyazawa *et al*., 2002). Another study from Nigeria showed that abundance of soil-inhabiting mites from cassava fields was different with seasonal variations.

The studies on the influence of different abiotic factor on the diversity of soil mites showed that these external factors have great impact on abundance of below-ground predatory Mesostigmata (Salmane, 2000; Hasegawa, 2001; Huhta and Hanninen, 2001; Xu *et al*., 2012). Similar studies regarding terrestrial ecosystem like grassland are limited (Cole *et al*., 2005, 2006, 2008; Briones *et al*., 2009; Wissuwa *et al*., 2012). It is considered that a strong link is present between below and above ground biodiversity. Further, the plant litter quality, quantity, soil moisture and microbes can control the abundance of soil-inhabiting arthropods (Hairiah *et al*., 2001).

Conclusions and Recommendations

The current study documented the soil-inhabiting mites in different localities of Dera Ghazi Khan, Pakistan. A total of 8 mite families were observed in four mango orchards intercropped with berseem and cotton. The current study also illustrated the impact of abiotic factors on the population fluctuation of soil mites during different months of the year. It can be concluded that orchards intercropped with various crops are rich source of soil inhabiting mites. Hence, other areas where fruit orchards are in abundant may be intercropped to enhance the diversity of soil inhabiting mites that could enhance the soil fertility.

Acknowledgement

We are thankful to Acarology research laboratory, University of Agriculture, Faisalabad for supporting the research activities. We are also grateful to anonymous reviewers for their valuable suggestions.

Novelty Statement

The study demonstrated the impact of different abiotic factors on the population fluctuation of soil mites from different mango orchards in Dera Ghazi Khan. The intercropped area encouraged the abundance of soil-inhabiting mites and found that some soil-inhibiting species also act as predators against insect pest species.

Author's Contribution

BSK and MA: Conceived the idea and initial write up of the experiment. Designed and performed the experiment.
AG and MF: had reviewed the experimental data and its analysis, Arrange the experimental data and did its analysis.
SU, SA and AR: Manuscript conclusion and technical input, initial analysis and sentence corrections of the manuscript text, had final draft reading and finalize discussion and references.

Ethics approval
Not applicable in this paper.

Conflict of interest
The authors have declared no conflict of interest.

References

Begum, F, R.M. Bajracharya, B.K. Sitaula, S. Sharma, S. Ali and H. Ali 2014. Seasonal dynamics and land use effect on soil microarthropod communities in the Mid-hills of Nepal. Inter. J.

Agron. Agric. Res., 5(2): 114-123.

Behan-Pelletier, V.M., 1999. Oribatid mite biodiversity in agroecosystems: Role for bioindication. Agric. Ecos. Environ., 74(1-3): 411-423. https://doi.org/10.1016/S0167-8809(99)00046-8

Behan-Pelletier, V.M., 2003. Acari and collembola biodiversity in Canadian agricultural soils. Can. J. Soil Sci., 83: 279-288. https://doi.org/10.4141/S01-063

Belaam-Kort, I., M.L., Moraza-Zorrilla, and S. Boulahia-Kheder. 2018. New records of soil mites (Acari) from citrus orchards of Tunisia.

Bonkowski, M., W. Cheng, B.S., Griffiths, J. Alphei and S. Scheu. 2000. Microbial-faunal interactions in the rhizosphere and effects on plant growth. Eur. J. Soil Biol., 36(3-4): 135-147. https://doi.org/10.1016/S1164-5563(00)01059-1

Briones, J.M., N.J. Ostle, N.P. McNamara and J. Poskitt. 2009. Functional shifts of grassland soil communities in response to soil warming. Soil Biol. Biochem., 41(2): 315-322. https://doi.org/10.1016/j.soilbio.2008.11.003

Carlsen, S.C.K. and I.S. Fomsgaard. 2008. Biologically active secondary metabolites in white clover (*Trifolium repens* L.) A review focusing on contents in the plant, plant pest interactions and transformation. Chemoecology, 18: 129-170. https://doi.org/10.1007/s00049-008-0402-7

Cohen, J.E., F. Briand and C.M. Newman. 2012. Community food webs: Data and theory (Vol. 20). Springer Science & Business Media.

Cole, L., M.A. Bradford, P.J.A. Shaw and R.D. Bardgett. 2006. The abundance, richness and functional role of soil meso and macro fauna in temperate grassland. A case study. Soil Biol. Biochem., 33: 186-198. https://doi.org/10.1016/j.apsoil.2005.11.003

Cole, L., S.M. Buckland and R.D. Bardgett. 2005. Relating micro-arthropod community structure and diversity to soil fertility manipulations in temperate grassland. Soil Biol. Biochem., 37: 1707-1717. https://doi.org/10.1016/j.soilbio.2005.02.005

Cole, L., S.M. Buckland and R.D. Bardgett. 2008. Influence of disturbance and nitrogen addition on plant and soil animal diversity in grassland. Soil Biol. Biochem., 40: 505-514. https://doi.org/10.1016/j.soilbio.2007.09.018

Culliney, T.W., 2013. Role of arthropods in maintaining soil fertility. Agricultue, 3: 629–659. https://doi.org/10.3390/agriculture3040629

Evans, G.O. and W.M. Till. 1979. Mesostigmatic mites of Britain and Ireland (Chelicerata: Acari Parasitiformes). An introduction to their external morphology and classification. Trans. Zool. Soc. London, 35: 145–270. https://doi.org/10.1111/j.1096-3642.1979.tb00059.x

Freckman, D.W. and R.A. Virginia. 1997. Low-diversity Antarctic soil nematode communities: distribution and response to disturbance. Ecology, 78(2): 363-369. https://doi.org/10.1890/0012-9658(1997)078[0363:LDASNC]2.0.CO;2

Gergócs, V. and L. Hufnagel. 2009. Application of oribatid mites as indicators. Appl. Ecol. Environ. Res., 7(1): 79-98. https://doi.org/10.15666/aeer/0701_079098

Gerson, U., R.L. Smiley and R. Ochoa. 2003. Mite (Acari) for Pest Control. Blackwell Science, Oxford, UK. https://doi.org/10.1002/9780470750995

Hairiah, K., S.E. Williams, D. Bignell, M. Swift and M. Noordwijk. 2001. Effects of land use change on belowground biodiversity. Bogor. Int. Cent. Res. Agrofores., pp. 32.

Hammer, O., D.A. Harper and P.D. Ryan. 2001. PAST: paleontological statistics software package for education and data analysis. Palaeontol. Electr., 4: 1–9.

Haq, M.A., 2007. Oriculture technology. A better tribute to crop production. J. Acaricol., 16(2): 100-103.

Hasegawa, M., 2001. The relationship between the organic matter composition of a forest floor and the structure of a soil arthropod community. Eur. J. Soil Biol., 37(4): 281-284. https://doi.org/10.1016/S1164-5563(01)01099-8

Hendrix, P.F. and C.A. Edwards. 2004. Earthworms in Agro ecosystems: Research approaches, Edwards, C.A. (Eds.) *Earthworm Ecology*, second ed. CRC Press, Boca Raton, London, New York, pp. 287-295. https://doi.org/10.1201/9781420039719.ch15

Huhta, V. and S.M. Hanninen, 2001. Effects of temperature and moisture fluctuations on an experimental soil microarthropod community. Pedobiology, 45(3): 279-286. https://doi.org/10.1078/0031-4056-00085

Jesus, M.B., I. Ostle, N.J. McNamara, N.P. and J. Poskitt. 2009. Functional shifts of grassland soil communities in response to soil warming. Soil Biol. Biochem., 41: 315-322. https://doi.org/10.1016/j.soilbio.2008.11.003

Khan, A.K., M.H. Bashir, B.S. Khan and N. Javed. 2017. Biodiversity of soil inhabiting Mesostigmata (Arachnida: Acari) from different agro-ecological zones of Punjab, Pakistan. Pak. J. Zool., 49(2): 677-683. https://doi.org/10.17582/journal.pjz/2017.49.2.677.683

Krantz, G.W. and D.E. Walter. 2009. A manual of acarology, 3rd ed. Texas Tech University Press, Lubbock.

Lindquist, E.E., 2003. Observations on mites of the subfamily Platyseiinae, with descriptions of two new species of Platyseius from North America (Acari: Mesostigmata: Ascidae). West Bloomfield, MI, Indira Publishing House, pp. 155–182.

Miyazawa, K., H. Tsuji, M. Yamagata, H. Nakano and T. Nakamoto. 2002. The effects of cropping systems and fallow managements on micro arthropod populations. Plant Prod. Sci., 5: 257-265. https://doi.org/10.1626/pps.5.257

Salmane, I., 2000. Investigations of the seasonal dynamics of Gamasina mites (Acari, Mesostigmata) in the pine forests of Latvia. Ekológia, 19(3): 245-252.

Sarwar, M., 2015. Mites (Acarina) as vectors of plant pathogens and relation of these pests to plant diseases. Agric. Biol. Sci. J., 1(4): 150-156.

Shannon, C.E., 1948. A mathematical theory of communication. Bell. Syst. Tech. J., 27: 379-423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x

Sharma, N. and H. Parwez. 2017. Seasonal Dynamics and Land Use Effect on Soil Micro Arthropod Communities in the Northern Indian State of Uttar Pradesh (India). Int. J. Appl. Agric. Res., 12(3): 371-379.

Shaw, M. and D.E. Walter. 2003. Hallowed hideaways: basal mites in tree hollows and allied habitats. In: Arthropods of tropical forests: Spatio-temporal dynamics and resource use in the canopy (eds. Basset, Y.V., Novotny, S.E., Miller, R.L., and Kitching. Cambridge University Press, Cambridge, UK. pp. 291–303.

Sirrine, J.R., D.K. Letourneau, C. Shennan, D. Sirrine, R. Fouch, L. Jackson and A. Mages. 2008. Impacts of groundcover management systems on yield, leaf nutrients, weeds and arthropods of tart cherry in Michigan, USA. Agric. Ecos. Environ., 125: 239-245. https://doi.org/10.1016/j.agee.2008.01.005

Urhan, R., Y. Katilmis and A.O. Kahveci. 2008. Vertical distribution of Mesostigmata (acari) in Dalaman (Mugla Prov. Turkey). Mun. Ent. Zool., 3(1): 333-341.

Wissuwa, J., J.A. Salamon and T. Frank. 2012. Effects of habitat age and plant species on predatory mites (Acari, Mesostigmataa) in grassy arable fallows in Eastern Austria. Soil Biol. Biochem., 50: 96-107. https://doi.org/10.1016/j.soilbio.2012.02.025

Xu, G.L., T.M. Kuster, M.S. Günthardt-Goerg, M. Dobbertin and M.H. Li. 2012. Seasonal exposure to drought and air warming affects soil Collembola and mites. PLoS One, 7(8): 43-102. https://doi.org/10.1371/journal.pone.0043102

Yahya, M., M. Afzal, M.Z. Majeed, I. Sarwar, K. Shehzad, M. Luqman and S.M. Shahzad. 2020. Differential impact of land-use, season and soil characteristics on the abundance of edaphic springtails (Insecta: Collembola) and mites (Arachnida: Acari). Pakistan J. Zool., 52: 1483-1491. https://doi.org/10.17582/journal.pjz/20190817120809