EFFECT OF SOIL PROPERTIES ON THE DIVERSITY AND DISTRIBUTION OF WEEDS IN CITRUS FARMS IN ARID REGION

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Abstract. The weed diversity and distribution in agroecosystems can be controlled by environmental variables. In this study, soil physical and chemical variables were investigated in three citrus farms located in the northern part of Saudi Arabia. A total of 12 soil physical and chemical variables were measured. Among the studied variables, only organic matter (OM), pH, phosphorus (P), calcium (Ca), bicarbonate (HCO_3) and sulphate (SO_4) were significantly different (one-way ANOVA at $P < 0.05$) among the three studied citrus farms. The regression model (Adj-R^2 = 0.416, P=0.024) showed that the organic matter (OM), calcium (Ca) and carbonate (CO_3) significantly affect the species richness of weeds. The multivariate model of CCA explained 68.64% of the variation of the taxonomic composition of weeds in citrus farms. It also revealed strong effect of soil texture (sand %), carbonate (CO_3), pH and sulphate (SO_4) on weed diversity and distribution. It was concluded that the soil physical and chemical properties are strong explanatory variables of the distribution of weeds in agroecosystems.
Keywords: *agroecosystem, ecology, weeds, environmental variables, Saudi Arabia*

Introduction

The problem of the weed invasion in the agroecosystems is considered as one of the most persistent problems threatening the agricultural productivity (Ramirez et al., 2018). The weeds are known as pests as they interfere with plant growth and potentially compete with the crops for light, water and nutrients (Chaudhary and Akram, 1987; Qasem and Hill, 1995; Storkey, 2006; Gomaa, 2012; Wang et al., 2013; Onen et al., 2018; Salehian et al., 2018). The invasion mechanisms of these weeds are still not fully understood. This is due to the complex interaction of weeds with the ecological and environmental settings in the agricultural ecosystem. However, many weed species exhibits remarkable adaptability to various environmental conditions (Onen et al., 2018; Salehian et al., 2018). Interestingly, there are evident reports that allochemicals secreted by the weeds eventually influence crop germination, growth and survival (Shah and Khan, 2006; Jabeen and Ahmed, 2009; Onen et al., 2018). Therefore, economic loss in agricultural production due to invasion of weeds in agricultural landscape is evident (Aldrich, 1984; Akobundu et al., 1987; Swanton et al., 1993; Khedr and Hegazy, 1998; Fayed et al., 1999; Al-Qahtani, 2018).

It is acceptable fact that the diversity and abundance of weeds in agricultural ecosystems are strongly correlated to the environmental conditions of the soil (Derksen et al., 1994; Andersson and Milberg, 1998; Thomas and Frick, 1993; Fried et al., 2008; Pinke et al., 2010; Ramirez et al., 2018). Furthermore, the diversity of weeds is also associated with variation in the crop cultivation practices and seasonality (El-Demerdash et al., 1997; Andersson and Milberg, 1998; Andreasen and Skovgaard, 2009).

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There is a high number of studies that addressed the interaction between plant diversity and the physical and chemical variables of the soil in different parts of the world including arid and semi-arid ecosystems particularly in Saudi Arabia (for instances see Al-Mutairi, 2017). However, most of these available studies focused on natural ecosystems and scarcely concentrated on agroecosystems. Several studies investigated the influence of soil's properties on diversity and distribution of plants such as Al-Mutairi (2017), Al-Masaudi et al. (2018) and Al-Robai et al. (2018). Despite the importance of weeds diversity and abundance in agricultural ecosystems, scarce number of studies were conducted in this context especially those tackled the influence of environmental conditions on the diversity of weeds (but see Al-Yemeny, 1999; Sher and Al-Yemeny, 2011). Most of the available studies aimed to describe the richness and abundance of weeds (see Gomaa, 2012, 2017). Similarly, Chaudhary et al. (1981) and Chaudhary and Akram (1987) provided a comprehensive study of weeds and their ecological and biological habitats in Saudi Arabia. In addition, similar studies were carried out at local scale. Shaltout and El-Halawany (1992) and El-Halawany and Shaltout (1993) studied the diversity patterns of weeds in the date palm farms of Al-Hassa Oasis in the eastern part of Saudi Arabia. Moreover, Al-Yemeny (1999), Sher and Al-Yemeny (2011) and Gazar (2011) described the diversity and taxonomic composition of weeds communities in dates palm orchards in the central part of Saudi Arabia.

The problem of weeds in citrus farms is threatening the production as it is associated with deterioration in fruits' quality and reduced productivity of the citrus trees. According to Al-Qahtani (2018), the common weed species reported in citrus farms in the northern part of Saudi Arabia are *Aizoon canariense*, *Artemisia seiberi*, *Morettia parviflora*, *Oxalis corniculata*, *Setaria viridis* and *Salsola imbricata*. In the same context, Gomaa (2017) reported that the common weed species in citrus farms are *Plantago lagopus, Cynodon dactylon, Imperata cylindrica and Convolvulus arvensis*. There are few common techniques to control weeds in citrus farms. However, these methods/techniques should be accompanied with proper ecological studies to better understand the biology and ecology of these invasive plant species (Al-Qahtani, 2018).

The information about the influence of soil's physical and chemical variables on diversity and distribution of weeds in citrus farms in arid region is incomplete. The study of Gomaa (2017) aimed to describe the species composition and diversity patterns of weeds in citrus farms without any significant efforts to address the possible effects of environmental variables. Therefore, the present study aims to investigate the influence of soil physical and chemical variables on diversity and distribution of weeds in citrus farms in Taymma (Saudi Arabia). This can be considered as pioneering effort to address the possible effect of environmental variables on diversity and distribution of weeds in agroecosystem of arid region (Saudi Arabia).

Materials and methods

Study site

Saudi Arabia has a large area of approximately 2 million km^2 and that constitutes a nearly 65% of the total area of the Arabian Peninsula. Terrestrial ecosystems are the predominant habitats which mainly consist of desert. The arid climate characterized with low annual precipitation (0-200 mm/year) and fluctuation in temperature regimes in different seasons (Al-Nafie, 2008; El-Sheikh et al., 2013).

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The study was conducted in three citrus farms located in Taymma of Tabuk region (*Fig. 1*). The climate of this region is arid and the temperature ranges from 0 °C in the winter to almost 50 °C during summer. The average annual precipitation is very low which can be less than 150 mm/year. Three citrus farms were selected based on possible accessibility (coordinates 27°34’37.5”N 38°33’48.4”E, 27°32’58.4”N 38°33’59.6”E, 27°34’59.4”N 38°33’33.5”E). The agricultural practices and manures are conventional and no special techniques/methods are applied by farmers. During the cultivation, few pesticides are applied to control mites as well as other insects (e.g. systemic pesticides). Prior permission to carry out the study in those farms was obtained from the owners. The three selected farms (sites) named; Site A, Site B and Site C experience similar regimes and agricultural practices. According to the statements from the farms owners, there was no control/management effort of these weeds in the studied sites.

Surveying the weeds communities

The weeds species were surveyed in the studied sites during the spring of 2018. At each citrus farm, weed species were observed and recorded using the commonly used techniques of 10 × 10 m stands in five randomly selected sites. The species data was recorded as presence/absence data. The specific taxonomical keys of Chaudhary et al. (1981), Chaudhary (2001) and Collenette (1999) which are the main keys of plant species in Saudi Arabia were used to identify the reported weed species.

Soil physical and chemical properties

The physical and chemical variables of the soil in the selected sites were measured. In each site, five soil samples were collected at depth from 0 to 30 cm randomly in March-May 2018. The collected samples were transferred into polyethylene bags and then labelled appropriately. Thereafter, the samples were transferred immediately to the laboratory. Then, extracts of the soil samples were prepared with distilled water at ratio of 1 to 5 following the procedures described previously in Al-Mutairi (2017). The percent of sand (%), conductivity (EC) and pH were measured accordingly. In addition, the soil samples were analyzed for phosphorus (P), Organic Matter (OM), Potassium (K), Sodium (Na), Calcium (Ca), Carbonate (CO_3), Bicarbonate (HCO_3), Sulphate (SO_4) and Chloride (Cl) following the standard methods and techniques as described earlier by Jacson (1965) and Allen et al. (1986).

Statistical analysis

All the statistical analyses were conducted using R program (version 12.4.1). The soil physical and chemical variables were analyzed descriptively for mean and standard error (SE). The one-way ANOVA was used to compare means of soil properties among the studied sites at $P < 0.05$. The function *lm* included in *vegan* package was used to determine the effects of soil variables on species richness. The adjusted regression coefficient (Adj-R^2) and significance level (P value) of the regression model were calculated. However, the multivariate analysis of Canonical Correspondence Analysis (CCA) was applied to examine the relationship between species distribution and the soil physical and chemical variables using the function *cca* in *vegan* package. The amount of species variation explained by the soil variables was calculated and expressed as the total variation explained (TVE) is defined as the sum of all eigenvalues divided by the total inertia (Ohmann and Spies, 1998).

Figure 1. *Map showing the location of Taymma (Tabuk region), Saudi Arabia. Geographical coordinates of the three selected farms are 27°34'37.5"N 38°33'48.4"E, 27°32'58.4"N 38°33'59.6"E and 27°34'59.4"N 38°33'33.5"E*

Results

The studied physical and chemical variables of the soil in the three citrus farms showed remarkable variability. The mean values of the studied soil physical and chemical variables are shown in *Table 1*. The organic matter (OM), pH, phosphorus (P), calcium (Ca), bicarbonate (HCO_3) and sulphate (SO_4) were significantly different (one-way ANOVA at $P < 0.05$) among the three studied farms.

Table 1. *Soil physical and chemical variables (mean ± SE) in citrus farms of Taymma (Tabuk, Saudi Arabia). The one-way ANOVA results show the mean comparison of the soil variables among the three studied sites. The significant values at P < 0.05 are indicated with asterisk*

Variable	**Site A**	**Site B**	**Site C**	**ANOVA $F_{2,14}$**
Geographical coordinates	27°34'37.5"N 38°33'48.4"E	27°32'58.4"N 38°33'59.6"E	27°34'59.4"N 38°33'33.5"E	-
Organic Matter (OM) (%)	0.480±0.515	2.756±2.203	3.064±1.456	4.127*
Electronic conductivity (EC) (ms/cm)	1288.400±234.884	1387.800±70.645	1370.800±272.343	0.316
pH	7. 32±0.279	7.386±0.245	7.904±0.188	6.034*
Potassium (K) (mg/l)	0.570±0.143	0.480±0.087	0.348±0.173	3.223
Sodium (Na) (mg/l)	1.872±0.383	2.158±0.417	2.012±0.131	0.908
Phosphorus (P) (mg/l)	13.600±1.817	22.400±6.656	10.200±2.280	11.261*
Calcium (Ca) (mg/l)	0.115±0.017	0.160±0.051	0.106±0.044	3.641*
Carbonate (CO_3) (mg/l)	0.094±0.101	0.082±0.056	0.012±0.027	2.095
Bicarbonate (HCO_3) (mg/l)	2.240±0.225	1.898±0.159	1.340±0.209	25.783*
Sulphate (SO_4) (mg/l)	7.574±0.864	3.594±0.562	5.880±0.885	32.428*
Chloride (Cl) (mg/l)	0.346±0.280	0.174±0.082	0.140±0.131	1.786
Sand (%)	83.154±1.385	81.886±4.286	77.528±6.956	1.902

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In this study, a total of 36 of weed species belong to 20 families were reported from three citrus farms in Taymma (Tabuk, Saudi Arabia; see *Appendix*). The linear regression model was applied to investigate the relationship between species richness (total number of species) and the soil physical and chemical variables. The regression model was significant and the adjusted regression coefficient (Adj-R^2 = 0.416, $F_{2,12}$ = 7.32 and P = 0.024). Organic matter (OM), calcium (Ca) and carbonate (CO_3) were the most important variables that showed significant relationship with weeds species richness.

The multivariate analysis of canonical correspondence analysis (CCA) was employed to determine the relationship between soil variables and distribution of weeds in citrus farms. *Figure 2* exhibited the triplot of CCA. The total inertia of the CCA model was 3.077 and the sum of canonical eigenvalues was 2.112. The amount of variation explained by the canonical eigenvalues can be calculated as the "total variance explained (TVE)". Here, the TVE was 68.64%. This implies moderately, yet strong relationship between variation in the soil variables and distribution of weeds in citrus agroecosystem.

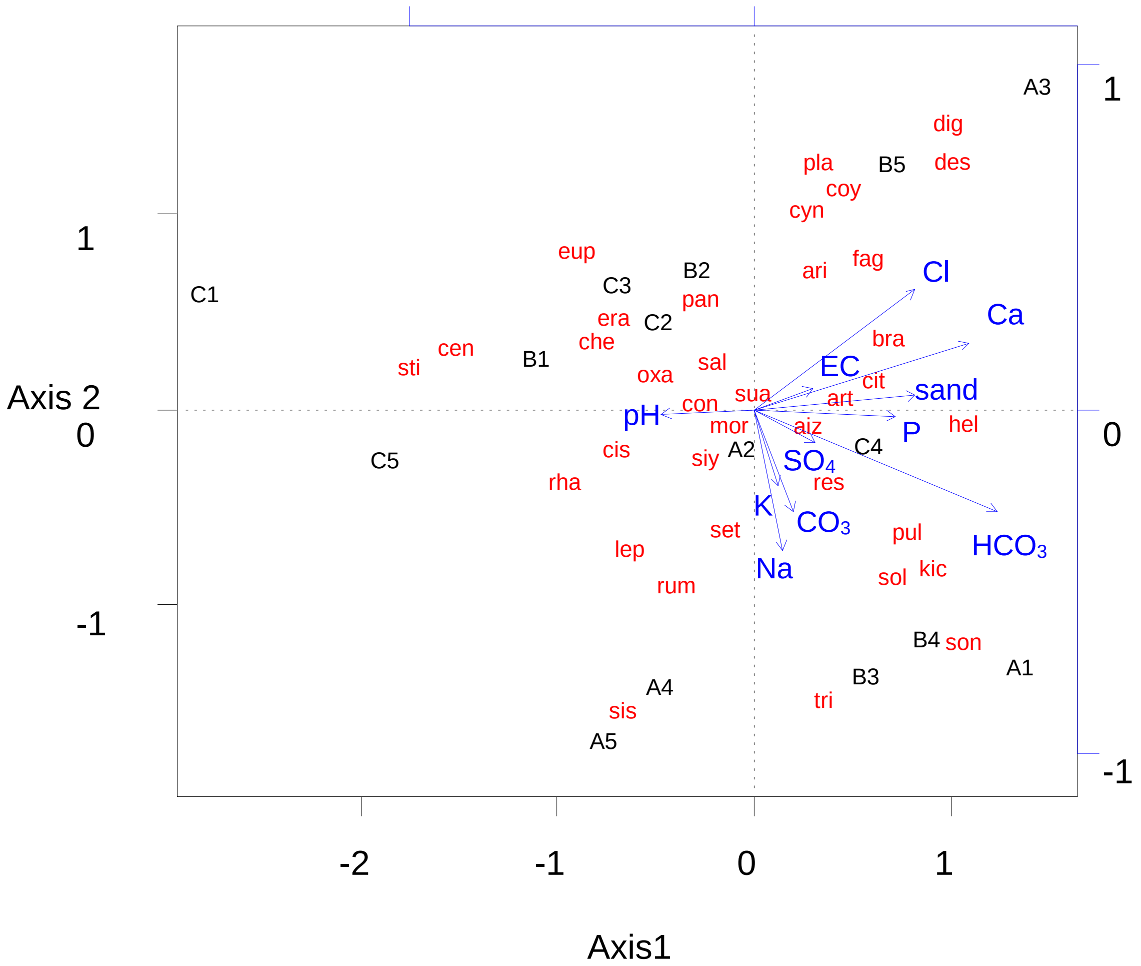

Figure 2. *Triplot of Canonical Correspondence Analysis (CCA) showing the correlation between soil physical and chemical variables and distribution of weeds in citrus farm of Taymma (Tabuk, Saudi Arabia). The first three letters of genus names are provided in the figure (see Appendix for full names). The organic matter (OM) was removed from the CCA plot as the eigenvalue was less than 0.1*

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Discussion

There is a relatively high diversity of weed species in citrus farms in this study as a total of 36 species were recorded. The total number of weeds species reported in this study was lesser than what have been reported in similar studies but different agroecosystems such as dates palm and olive orchards of al-Jouf (71 species, Gomaa, 2012), dates palm of Al-hassa (118 species, El-Halawany and Shaltout, 1993) and central part of Saudi Arabia (55 species, Gazer, 2011). However, this was higher compared to the study of Gomaa (2017) who reported 33 weed species in citrus farms in the northern part of Saudi Arabia.

The soil physical and environmental variables showed remarkable variability among the studied farms. The variables of organic matter, pH, phosphorus, carbonate, bicarbonate and sulphate were significantly different among the studied sites. This is in agreement with the study of Al-Mutairi (2017) who reported that organic matter, soil pH and calcium were significantly different among four studied sites in Tabuk region. This possible variation may be due to differences in the soil contents, and texture. The microhabitat of plants in agroecosystems is also affected by other possible factors such as the microflora in the soil especially microbial communities (Zak et al., 2003). Furthermore, the application of different fertilizers would surely result in significant variation in the organic matter contents.

However, Fried et al. (2008) found that the soil pH and soil texture are the most important factors structuring the weed communities in temperate region (France). On the other hand, some studies highlighted the agricultural practices are the main driver for diversity and abundance of weeds in agroecosystems (Rauber et al., 2018).

The species richness of weeds in citrus farms showed to be affected mainly by organic matter (OM), calcium (Ca) and carbonate (CO_3) of the soil as indicated by the adjusted regression coefficient of the linear regression model (Adj-R^2 = 0.416). Despite, a total of 12 environmental variables were included in the analysis, only the above three variables were significant in the regression model. The possible justification is that the environmental variables are not the only factors controlling the weeds communities in citrus farms as reported on other agroecosystems (see Rauber et al., 2018). Other biotic interaction may contribute in structuring the weeds communities in agroecosystems. These assumptions are supported by the fact that approximately 20-60% of variation in plant communities can be merely explained by environmental variables. The remaining unexplained variation can be related to other spatial and biological factors (Galal and Fahmy, 2012).

The multivariate analysis of canonical correspondence analysis is a reliable technique to reveal the complex relationship between species and environmental variables. In this study, the total variance explained (TVE) percentage ~~was~~ implied that the selected variables had the strength to explain the variation in the weed taxonomic composition in citrus farms (TVE = 68.64%). This amount of TVE is comparable with what have been reported in arid region (e.g Al-Mutairi, 2017). Soil texture (i.e. sand %), carbonate, bicarbonate, pH and sulphate should to be strong drivers controlling the structure of weed communities in citrus farms of Taymma. In general, this is in agreement with previous reports from arid and semi-arid ecosystems (Shaltout and El-Sheikh, 1993; Shaltout et al., 1994; Al-Sodany, 1998; Al-Mutairi, 2017).

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Conclusion

To conclude, the present study revealed that soil physical and chemical variables evidently affect the diversity and distribution of weeds in citrus farms in arid region at the northern part of Saudi Arabia. The species richness of weeds in citrus farms was significantly influenced by organic matter, calcium and carbonate contents in the soil. The CCA model showed strong effect of soil texture, carbonate, bicarbonate, pH and sulphate variables on distribution of weeds in agroecosystem. This reflects variation in the preference of weed species towards different environmental variables. It is suggested that further studies should be carried out in this region to better understanding of the invasion mechanisms of weeds in agricultural landscape. This certainly will improve the future management practices of weeds and minimize the agricultural production loss due to manifestation of weeds.

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APPENDIX

List of recorded weeds species from Tabuk, Saudi Arabia by Saelm M. Al-Qahtani

Latin name	Family	Life Form	Chorotype
Aizoon canariense	Aizoaceae	Herb	Somalia-Masai
Aristida adscensionis	Poaceae	Perennial grass	Saharo-Arabian
Artemisia seiberi	Asteraceae	Subshrub	Irano-Turanian
Brassica tournefortii	Brassicaceae	Herb	Mediterannean-Saharo-Arabian
Cenchrus ciliaris	Gramineae	Perennial grass	Tropical African
Chenopodium murale	Chenopodiaceae	Herb	Paleotropic
Citrullus colocynthis	Cucurbitaceae	Herb	Saharo-Arabian
Citrus sinensis	Rutaceae	Shrub	Chinese
Convolvulus arvensis	Convolvulaceae	Subshrub	Tropical
Conyza bonariensis	Asteraceae	Herb	American
Cynodon dactylon	Poaceae	Perennial grass	Tropical
Desmostachya bipinnata	Poacea	Perennial grass	Saharo Arabian-Somalia Masai
Digera muricata	Amaranthaceae	Herb	Paleotropic
Eragrostis barrelieri	Poaceae	Perennial grass	Mediterannean-Saharo Arabian

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Euphorbia peplis	Euphorbiaceae	Herb	Mediterannean-Euro Siberian-Irano-Turanian
Fagonia bruguieri	Zygophyllaceae	Subshrub	Saharo Arabian
Heliotropium bacciferum	Boraginaceae	Subshrub	Saharo Arabian-Somalia Masai
Kickxia aegyptiaca	Scrophulariaceae	Subshrub	Saharo Arabian
Lepidium africanum	Brassicaceae	Herb	Tropical African
Morettia parviflora	Brassicaceae	Subshrub	Samalia Masai
Oxalis corniculata	Oxalidaceae	Subshrub	Tropical
Panicum coloratum	Poaceae	Perennial grass	American
Plantago lanceolata	Plantaginaceae	Herb	Mediterannean-Euro Siberian-Irano-Turanian
Pulicaria undulata	Asteraceae	Subshrub	Saharo Arabian-Somalia Masai
Reseda muricata	Resedaceae	Herb	Saharo Arabian
Rhanterium epapposum	Asteraceae	Subshrub	Saharo Arabian
Rumex dentatus	Polygonaceae	Subshrub	Mediterannean-Euro Siberian-Irano-Turanian
Salsola imbricata	Chenopodiaceae	Subshrub	Saharo Arabian
Setaria viridis	Poaceae	Annual grass	Mediterannean-Euro Siberian-Irano-Turanian
Sisymbrium erysimoides	Brassicaceae	Herb	Saharo Arabian-Mediterannean
Sisymbrium irio	Brassicaceae	Herb	Mediterannean-Euro Siberian-Irano-Turanian
Solanum nigrum	Solanaceae	Herb	Mediterannean-Saharo Arabian
Sonchus oleraceus	Asteraceae	Herb	Mediterannean-Euro Siberian-Irano-Turanian
Stipagrostis plumosa	Poaceae	Perennial grass	Saharo Arabian-Irano Turanian
Suaeda vermiculata	Chenopodiaceae	Subshrub	Saharo Arabian
Trigonella anguina	Leguminosae	Herb	Saharo Arabian

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