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Agro ecological assessment of Siwa Oasis arable lands

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Abstract

A critical foundation of sustainable agriculture is to understand different agro-ecosystems components and to investigate relations between different species and environmental factors affecting their presence and expansion. The flora of Siwa Oasis agro-ecosystems was investigated and assessed. A total of 132 stands (66 in spring and another 66 in summer) were chosen to represent the study area and its soil properties during spring and summer. Cover of each species and foliage projective cover of each stand was visually estimated. Species richness, diversity and evenness were calculated for each stand. Soil analyses showed that stands could be differentiated geographically. Vegetation and soil relationships were explored using different ecological multivariate techniques. TWINSPAN classification resulted in four ecological groups in spring and four more groups in summer. DCA and DCCA clustered stands in a similar manner to the ecological groups extracted from TWINSPAN classification. Indicator species and correlated soil characteristics of each group were identified. Salinity, crop type, water availability, shade and human intervention are the major factors affecting the diversity and richness of the vegetation communities in Siwa Oasis cultivated land. Some of the species recorded are of high economic importance, highlighting a valuable opportunity to cultivate problematic soils with non-traditional crops.

***Keywords**:* Siwa Oasis, sustainable agriculture, diversity, weeds, crop, classification.

Introduction

The combination of ecology and agronomy has evolved the science of agro-ecology where agro ecosystem is the heart of it (Gliessman, 1990). What differs an agro ecosystem from a natural ecosystem is that the first is a result of dynamic correlation between all forms of human activities, including socioeconomic status, and different biotic and abiotic components of the agro-ecosystem (El-Bakry, 1982). Energy loss, nutrient removal and application of different sorts of chemical fertilizers and pesticides are affecting agro ecosystems function and structure (Dighton and Krumins, 2014). Reduction of species diversity, alteration of soil food web, changing the availability of different elements and habitat loss are some of the consequences of ecosystem conversion (Cheeke *et al.*, 2012; Moore and de Ruiter, 2012). All of these effects have necessitated the quest for more sustainable practices in agriculture (Perfecto and Vandermeer 2010; Médiène *et al.* 2011 and Wezel *et al.*, 2014). On the formal level, the second goal of the 2030 Agenda of sustainable development adopted by the United Nations General Assembly (GA) has considered promoting sustainable agriculture as a major goal in order to end the world hunger and achieve global food security (UN General Assembly, 2015).

Understanding species interactions within agro ecosystems is one of the major concepts in sustainable agriculture (Malézieux *et al.* 2009). Interactions may be positive (e.g. facilitation) or negative (e.g. competition) (Vandermeer, 1989). Identification of different interactions is very significant in obtaining appropriate agricultural practices. Weeds are fast growing plants that can grow and flourish in disturbed environments (Stepp, 2004). Weed competition with cultivated species over resources may cause a great loss in crop yield (Buchanan *et al.*, 2000). Diversity and richness of weed communities are affected with different parameters. Water and soil quality, crop type, crop rotation, application of chemicals are some of these factors (Pysek and Lepš 1991; Derksen *et al.* 1994; Leeson *et al.* 2000). Several studies have been conducted to investigate the weed flora from a phytosociological and ecological point of view (Hegazy *et al.,* 2004; El-Gawad *et al.,* 2014; Shehata *et al.,* 2014; Mashaly *et al.,* 2015; Salama *et al.,* 2016 and Renton and Chauhan, 2017).

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Siwa Oasis agriculture is unique due to its distinctive water source and isolation within the hyper-arid Western Desert of Egypt (Henning and Flohn, 1977 and Kuper and Kröpelin, 2006). Agriculture is utterly dependent upon artesian supplies derived from the Nubian Sandstone Aquifer System (NSAS). Salinity varies across the system and Siwa is situated over an area of brackish supply extending north over the Qattara Depression (Himida, 1970). The large amounts of soluble salts in Siwa's water supply makes it more suitable for the irrigation of halo-tolerant species. Date palms and olives followed by alfalfa are the main cultivated species in Siwa Oasis due to their salt tolerance (Salheen, 2011).

Mismanagement of Siwa's natural resources has triggered several ecological problems. The Agricultural administration of Siwa Oasis (2015) has identified desertification, water and soil salinity, water waste, water logging and excessive use of agricultural chemicals, to be of critical concern. This is in addition to some pests and diseases that harm palms and olives such as the red palm weevil (*Rhynchophorus ferrugineus*), weeds related issues are another complex problem.

The present work aims to define plant communities and weed assemblages of Siwa Oasis agro-ecosystems and the environmental factors affecting species distribution patterns in completion to our previous work on the vegetation of Siwa Oasis agro-ecosystems (El-Saied *et al.*, 2015). Special interest was given to plant indicators and vegetation-environment relationships. This work is important in devising regional strategies for land-use and productivity to cope with the increasing salinity and rising water tables.

Material and methods

Vegetation analysis

A total of 132 stands (66 stands during spring and another 66 different stands during summer of the same year) were chosen to represent Siwa Oasis agro-ecosystems. This study was conducted from October 2013 to May 2015. Stands were subjectively chosen to represent the vegetation of different cultivation types. GPS coordinates of these stands are shown in (Fig. 1). Species occurring in four 25 m^2 quadrats within each stand were recorded. A Full list of species was provided in our previous work (El-Saied *et al.,* 2015). Visual estimation of each species coverage in percentage and the percentage of bare soil in each quadrat were obtained. Canopies cover was visually estimated to provide a shade measurement of each quadrat (foliage projective cover). Species richness (Alpha diversity) was calculated during spring and summer after Whittaker (1972). Species diversity was determined during spring and summer using the Shanon Index. Evenness was calculated after Pielou (1966).

Soil analyses

For each of the 132 stands, four soil samples were collected at a depth of 0-25 cm. The four samples were pooled to form one composite sample. A total of eighteen soil physical and chemical parameters were determined: mechanical analysis, moisture content, electrical conductivity, total dissolved salts, pH, carbonates, bicarbonates, chlorides, organic carbon, organic matter, nitrates, nitrites, sulfates, sodium, potassium, calcium, magnesium and phosphorus. Moisture content was measured within 48 hours of the collection time. Mechanical analysis of the samples was achieved to detect soil texture using sieves of different sizes to detect gravel, coarse sand, fine sand, very fine sand, while pipet analysis method was used for the separation of silt and clay particles. Samples were sieved at 2mm sieve and air dried for further analyses. Soil extract 1 soil: 5 distilled water (weight/volume) was prepared for all samples and different water soluble parameters were detected. Non water soluble parameters were measured either in a digested or non-treated soil. All soil analyses have been conducted in the Ecology Laboratory, Faculty of Science, Al-Azhar University.

Data analysis

We used the data to define relationships among species, stands and environmental factors during spring and summer, and to detect which environmental factors affect the distribution of species. Defining different ecological groups of species and ecologically similar stands was also of great interest. In order to achieve this, different statistical packages including PC-ORD ver. 5 (Data profile, TWINSPAN and DCA; McCune and Mefford, 1999) and CANOCO ver. 4.5 and CanoDraw ver 4.1 (DCCA; ter Braak, 1988) were employed.

A data profile is a summary statistics that describes some important properties of the data which might be used to decide which data manipulation is needed and which analysis is to be used. One of the properties to be obtained from the data profile provided by the PC–ORD package is the Whittaker`s Beta diversity (Bw) which implies the necessity of applying data transformation or relativization for the original data. Beta diversity, Whittaker`s (Bw) is calculated only for species data depending on presence/absence data. Bw value was 6.8 for spring and 6.1 for summer. It was necessary though as the Bw was higher than 5 to apply data modification as it was recommended by the program to reduce the Bw. Different transformations were applied to find the best one to suit our data. Deletion of outlier stands in spring and summer seasons was of high impact and showed the best results in both cluster analysis and ordination. Average distance was calculated for each matrix. Sørensen distance was used for community data, while Euclidean distance was used for environmental data. Sørensen distance is expressed by percentage. Potential outliers among the stands and species in the community matrices and different environmental factors in the non-community matrices were identified. In general, stands outliers are more important than species or environmental factors outliers as the first is most likely to have undue influence on different analyses. Potential outliers might be removed to sharpen the results or to avoid odd results. Potential outliers in stands were removed before analysis; stands 34 and 51 were removed from spring data and stands 122, 129 and 130 from summer data.

Two–way indicator species analysis (Hill, 1979 and Gauch and Whittaker, 1981), a divisive cluster analysis method, was used to identify ecological groups using species coverage data.

Two ordination techniques were applied, DCA (indirect gradient analysis) and DCCA (Direct gradient analysis), to detect the indicator species and environmental factors that characterize different ecological groups and to investigate species patterns in relation to different environmental factors.

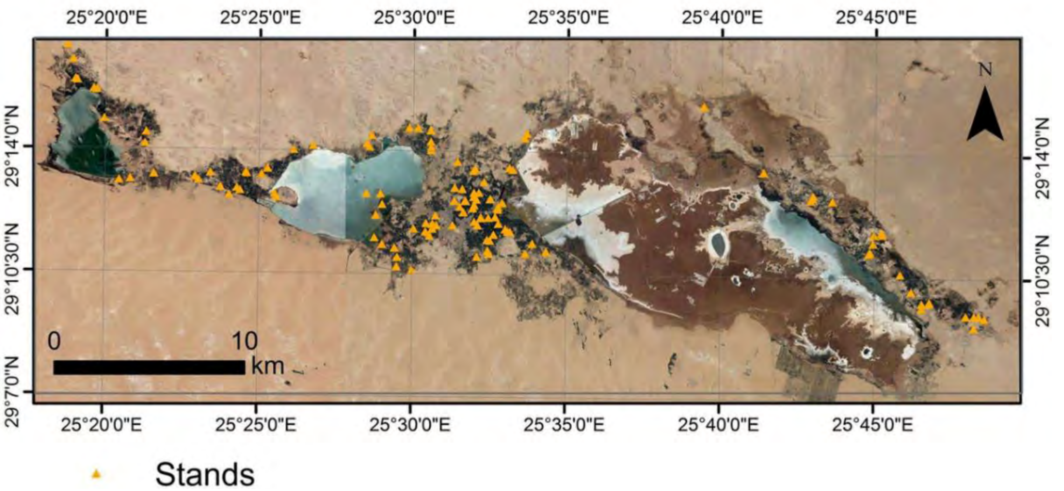

Fig. 1. Location map of the 132 stands sampled in Siwa Oasis during spring and summer seasons.

Results

In the first part of this work, a full list of species including life forms and chorology of the recorded species were provided. An insight into vegetation composition changes was achieved by cross referencing with previous records. A total of 102 wild taxa belonging to 34 families and 90 genera were recorded in Siwa Oasis, out of which 55 species were not recorded in previous studies. A total of 100 species were recorded in spring while only 33 species were recorded in summer. Asteraceae, Poaceae and Fabaceae were the most common families. Seven life forms were recorded where therophytes were the prevailing group, followed by hemicryptophytes, chamaephytes, phanerophytes, geophytes, helophytes, and parasites. From a phytogeographical point of view, the recorded species were classified into: monoregional, bioregional, pluriregional, palaeotropical or cosmopolitan. In addition to the wild taxa, 52 cultivated species were recorded (El-Saied *et al.*, 2015).

Vegetation analysis showed that all diversity indices were higher in spring than in summer. Soil analyses results showed that all salinity indicators averages were higher in summer than in spring except for calcium and magnesium. On the other side, fertility indicators averages were higher in winter than in summer. Results of the mechanical analysis showed that soil texture may be sandy, loamy sand or sand loamy. Sand particles are the major content in all studied stands (over 90%). Silt particles recorded less than 10 % of samples collected in all stands, except for 4 stands. Clay particles recorded less than 10 % in all stands except for a single stand. A brief description of different environmental parameters and vegetation indices during spring and summer is provided in (Table 1).

Table 1. Environmental parameters and vegetation indices during spring and summer at 132 stands, Siwa Oasis. Mean values are shown with range in brackets

Environmental parameter	Spring stands (n=66)	Summer stands (n=66)
Gravel (%)	12.59 (0.3-34.7)	5.72 (0.008-25.6)
Coarse sand (%)	56.46 (38.8-72.8)	49.70 (19.2-68.2)
Fine sand (%)	24.90 (6.6-47.2)	34.48 (14.9-65.1)
Very Fine sand (%)	3.06 (0.3-11.55)	5.07 (0.3-16.4)
Silt (%)	1.56 (0.2-8.3)	2.72 (0.1-12)
Clay (%)	1.39(0.2-5.92)	2.27 (0-12.4)
Soil moisture content (%)	14.51(2.8-31)	12.43 (1.2-39.4)
Soil pH	8.58 (8.1-9.3)	8.46 (7.5-9)
Carbonates (%)	1.36 (0.73-2.28)	0.88 (0.7-2.23)
Bicarbonates (%)	0.44 (0.3-0.91)	0.48 (0-0.915)
Organic carbon (%)	2.81 (0.7-5.1)	0.55 (0-2.4)
Organic matter (%)	4.84 (1.20-8.77)	0.95 (0-4.128)
Soil electrical conductivity (mS/cm)	1.72 (0.20-10.70)	1.79 (0.28-13)
Total dissolved salts (ppm)	1101.54 (130-6850)	1148.04 (184-8350)
Chlorides (mg/L)	5.95 (1.1-104.4)	19.70 (1.2-320)
Calcium (mg/L)	9.46 (3-28.3)	5.23 (2-15)
Magnesium(mg/L)	9.56 (2-54.6)	7.50 (0-55)
Sodium (mg/L)	66.77 (2.42-263.6)	357.23 (172.2-576)
Potassium (mg/L)	3.84 (1.57-10.56)	10.24 (2.9-32)
Sulphates (ppm)	74.10 (47-77)	74.31 (61-78)
Nitrate (ppm)	1.36 (0.73-2.28)	0.88 (0.708-2.234)
Nitrite (ppm)	40.14 (2.28-192.24)	26.75 (2.64-199.79)
Phosphorus (mg/L)	4.69 (2.52-5.99)	4.56 (0.16-25.21)
Altitude (asl)	-4.84 (-19-13)	-8.80 (-22-3)
Bare soil (%)	58.61 (6.95-91.58)	38.03 (11.96-80.93)
Foliage projective cover (%)	25.62 (0-71.3)	16.01 (0-56.3)
Species richness	14.53 (4-25)	9.58 (4-19)
Shannon index (Species diversity)	1.63 (0.57-2.38)	1.31 (0.067-2.18)
Evenness	0.33 (0.11-0.48)	0.31 (0.016-0.52)

TWINSPAN

TWINSPAN has divided the 4 stands of Siwa Oases during spring season (after removing the two outlier stands) using pseudospecies cut levels 0, 0.5, 1, 3, 5, 10, 15, 25 and 50 into four ecological groups (00, 010, 011 and 1). (Fig. 2). During summer and based on pseudospecies cut levels 0, 0.5, 1, 5, 10, 15, 20, 40 and 60, TWINSPAN has divided the 63 stands (after removing the three outlier stands) into four vegetation groups (00, 010, 011 and 1) (Fig. 3). Each cluster has one or more indicator species which characterize that particular habitat according to the most distinctive species and the most abundant characteristic species that reached the highest cover values.

Detrended Correspondence Analysis (DCA)

DCA was applied to both spring and summer data of Siwa Oasis and results were plotted on Axes 1 and 2; a joint plot (biplot) was presented to show stands in relation to species (Fig. 4A) and in relation to environmental factors (Fig. 4B) in spring and (Fig. 5A and B) in summer. When plotted on the first two DCA axes, stands tended to cluster into the four vegetation groups resulted from TWINSPAN.

In relation to environmental factors, results of spring showed positive correlation with axis 1 and sulfates, nitrate, pH and foliage projective cover. Meanwhile, results showed positive correlation with axis 2 and organic matter, altitude and Alpha diversity. Moreover, results showed negative correlation with axis 1 and moisture content, carbonates, phosphorus, magnesium, sodium, chloride, calcium, total dissolved salts, and electrical conductivity, also results showed negative correlation with axis 2 and nitrite, Shannon index and bare soil.

Regarding vegetation data, *Chenopodium album* and *Sonchus oleraceus* were positively correlated with axis 1, while *Medicago sativa, Silybum marianum, Cynanchum acutum, Triticum vulgare* and *Zygophyllum album* were positively correlated with axis 2. *Tamarix nilotica, Samolus valerandi, Cyperus rotundus, Typha domingensis, Phoenix dactylifera, Olea europaea, Ruppia cirrhosa, Apium nodiflorum, Mentha longifolia* and *Arthrocnemum macrostachyum* were negatively correlated with axis 1, while *Lolium perenne, Ziziphus spina–christi, Chenopodium murale, Imperata cylindrica, Brassica rapa* and *Phragmites australis* were negatively correlated with axis 2.

TWINSPAN Groups (011 and 010) were positively correlated with axis 2, while group (00) was negatively correlated with axis 2. Group (1) was negatively correlated with axis 1.

During summer and in relation to environmental data, results showed that alpha diversity was positively correlated with axis 1, while total dissolved salts, electrical conductivity, magnesium, calcium, carbonates, foliage projective cover and moisture content were negatively correlated with axis 1. On the other hand, magnesium, calcium and sulfates were positively correlated with axis 2, while carbonates, organic matter and organic carbon were negatively correlated with axis 2.

In relation to vegetation data, *Cynodon dactylon, Ficus carica* and *Punica granatum* were positively correlated with axis 1, while *Juncus rigidus, Phragmites australis, Tamarix nilotica, Arthrocnemum macrostachyum, Imperata cylindrica, Phoenix dactylifera, Cyperus rotundus* and *Bacopa monnieri* were negatively correlated with axis 1, on the other hand, *Medicago sativa* was positively correlated with axis 2 while, *Corchorus olitorius* was negatively correlated with axis 2.

Group (011) was positively correlated with axis 1, while Group (1) was negatively correlated with axis 1. On the other hand, Group (00) was positively correlated with axis 2, while Group (010) was negatively correlated with axis 2.

Detrended Canonical Correspondence Analysis (DCCA)

DCCA was applied to all data of Siwa Oasis during spring and summer seasons and results were presented in Fig. (6A and B).

In spring, group 1 showed a positive correlation with total dissolved salts, electrical conductivity, sodium, potassium, calcium, magnesium, chlorides, nitrite, carbonates, bicarbonates, gravel and moisture content. Group 00 showed a positive correlation with nitrate, pH, fine and coarse sand. Group 010 and group 011 showed a positive correlation with altitude, alpha diversity, moisture content, clay, silt, carbonates and bicarbonates.

DCCA ordination diagram of Siwa Oasis (summer data) showed that group 011 has a positive correlation with calcium, chlorides, fine sand, very fine sand and total sand. Group 00 showed a positive correlation with total dissolved salts, electrical conductivity, magnesium and potassium. Group 1 showed a positive correlation with foliage projective cover, Shanon index, species evenness, altitude, moisture content, gravel, coarse sand, carbonates, bicarbonates, organic carbon and organic matter. Group 010 showed a positive correlation with alpha diversity, silt, clay, pH, nitrates and nitrites.

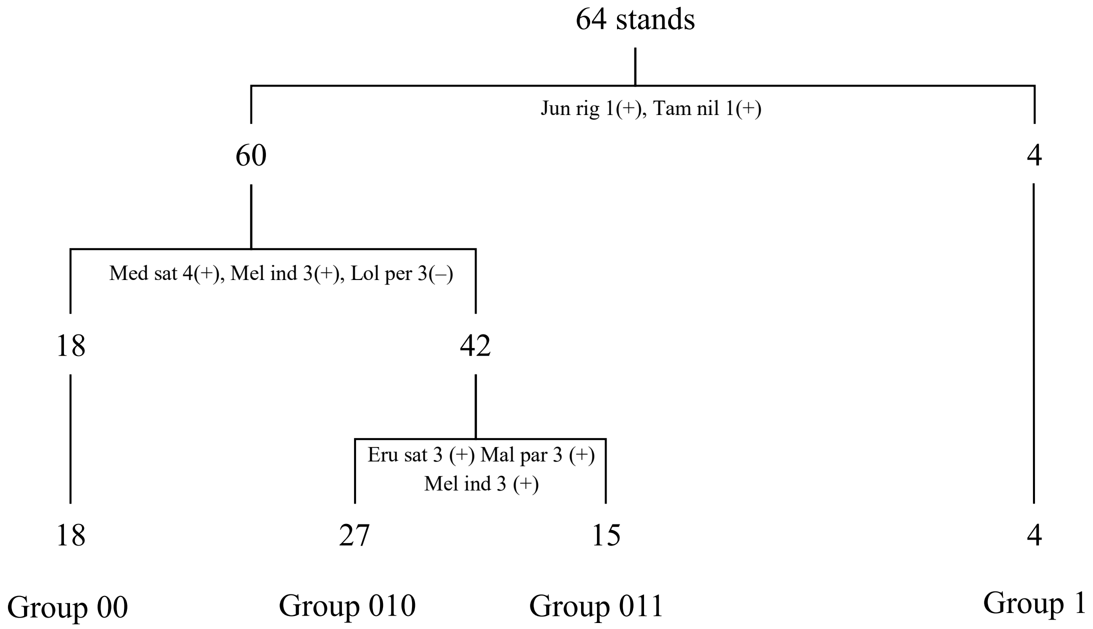

Fig. 2. TWINSPAN classification for the vegetation of the selected 64 stands (after removing two outliers) in Siwa Oasis during spring. 00, 010, 011, 1 were the four separated vegetation clusters. Indicator species for each cluster were listed (for abbreviations, see appendix).

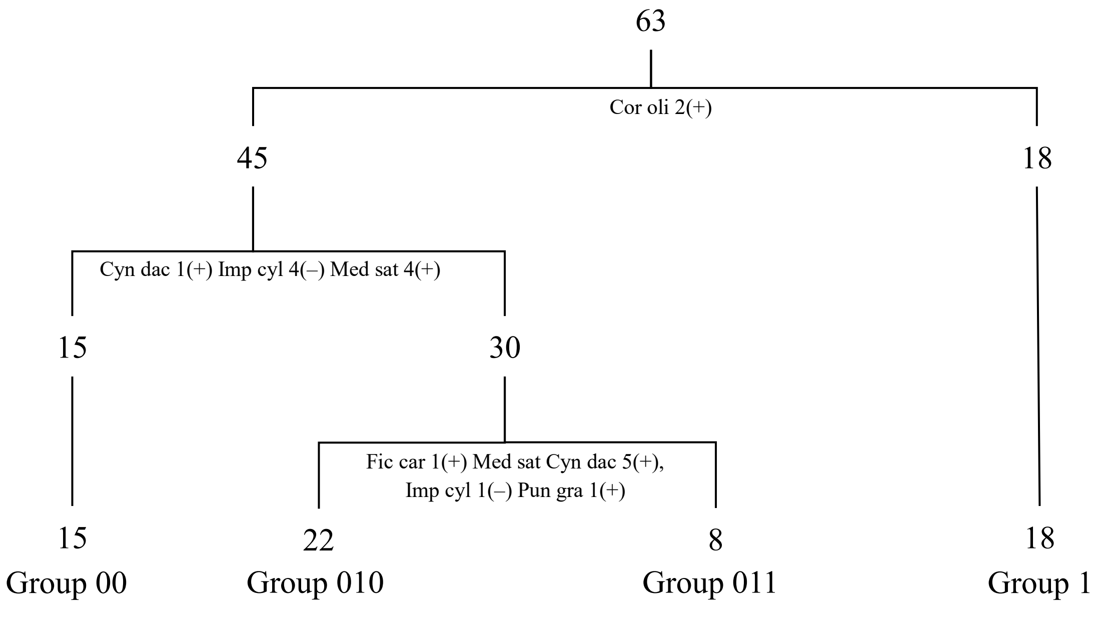

Fig. 3. TWINSPAN classification for the vegetation of the selected 63 stands (after removing three outliers) in Siwa Oasis during summer. 00, 010, 011, 1 were the four separated vegetation clusters. Indicator species for each cluster were listed (for abbreviations, see appendix).

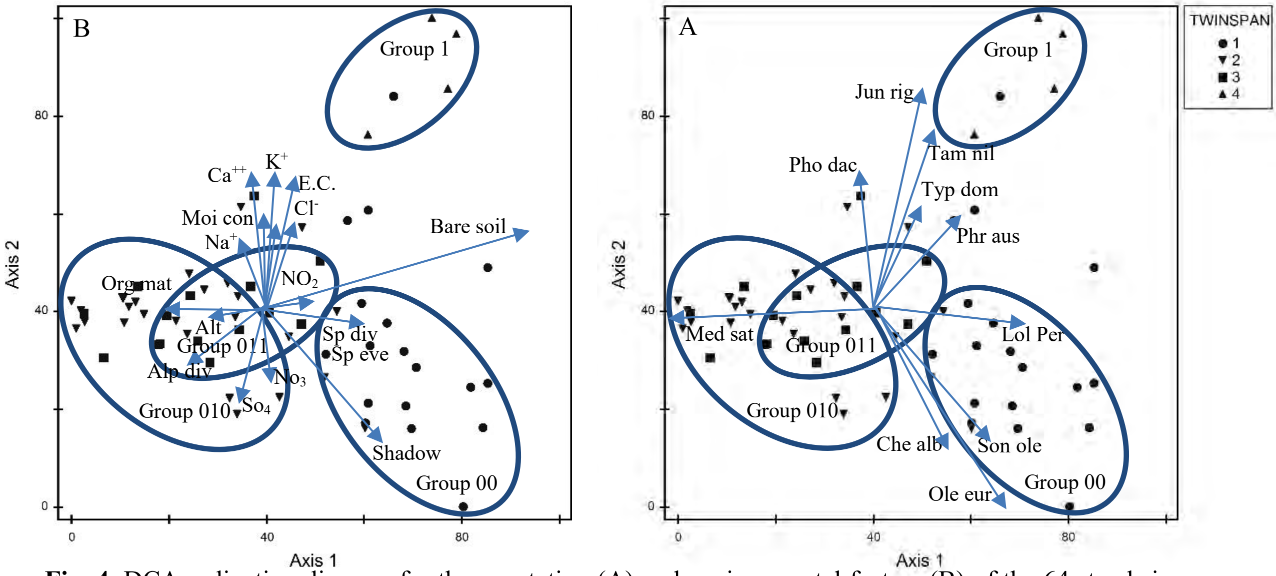

Fig. 4. DCA ordination diagram for the vegetation (A) and environmental factors (B) of the 64 stands in Siwa Oasis during spring on axes 1 and 2, with TWINSPAN groups superimposed.

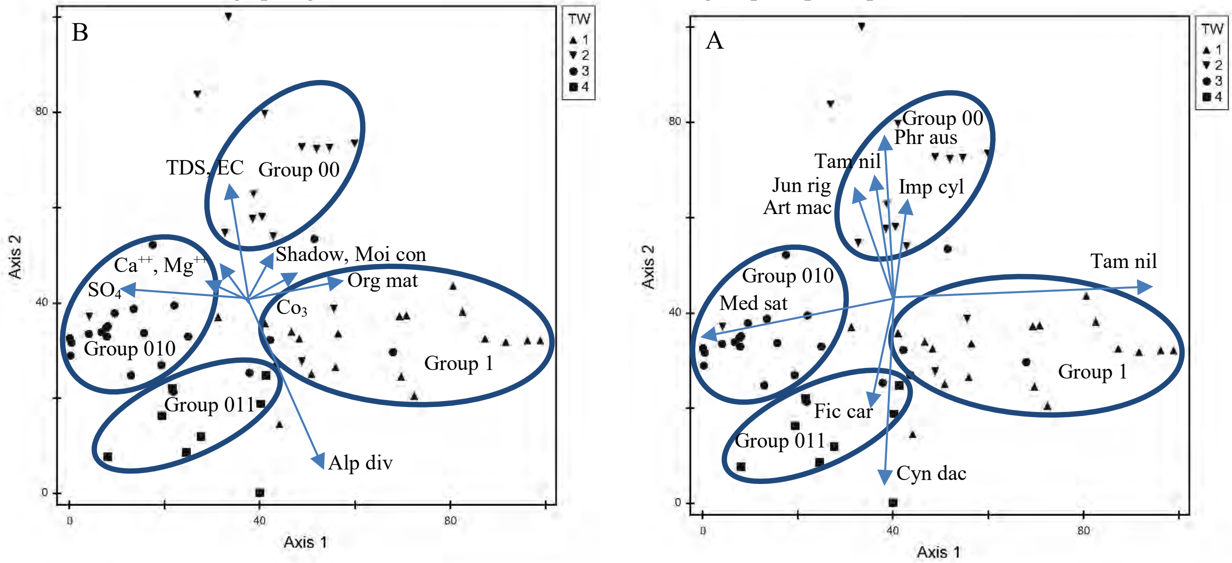

Fig. 5. DCA ordination diagram for the vegetation (A) and environmental factors (B) of the 63 stands in Siwa Oasis during summer on axes 1 and 2, with TWINSPAN groups superimposed.

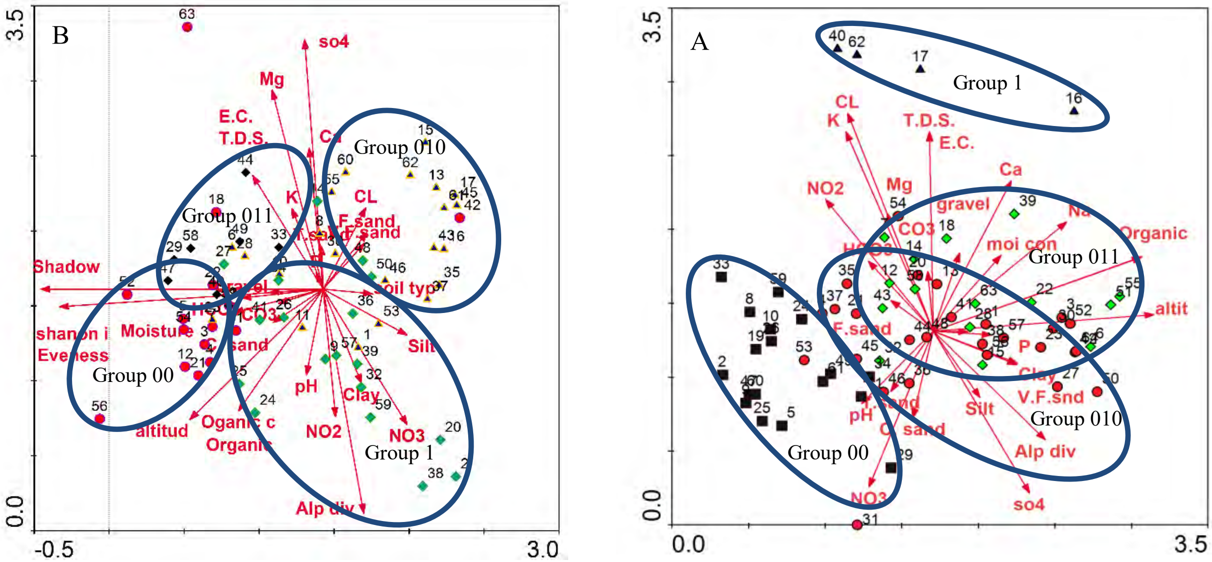

Fig. 6. DCCA ordination of the first two axes showing the distribution of the 64 stands in Siwa Oasis during spring (A) and during summer (B) with their TWINSPAN clusters in relation to different environmental factors (for abbreviations, see appendix 1).

Discussion

Soil analyses

Generally, results of soil analyses showed that Siwa Oasis could be divided into three regions or provinces; the old city (Shali) in the middle of Siwa and the other two extensions, one to the east and the other to the west.

The present work confirms other studies highlighting high salinity problem in Siwa Oasis (Zahran, 1972; Abd El-Ghani, 2000; William, 2004; Masoud and Koike, 2006; El-Nagar, 2008 and Farrag *et al.*, 2016). Soil moisture content and almost all salinity indicators (such as T.D.S, E.C, Mg^{++}, Ca^{++}, Na^{+}, K^{+} and Cl^{-}) were higher in the eastern part of the Oasis than in the western part or even in the old city of Shali which may be due the fact that the western part is at higher altitude than the eastern part. Soil salinity can severely affect plant growth and land use and increase soil erosion (Hazelton and Murphy, 2007). El-Nagar (2008) has mentioned that the soil quality is affecting peoples' attitude in Siwa Oasis and that the eastern part of Siwa is considered to be unfavorable place for most of the inhabitants as it is full of Sabkhas, salt marches and saline water. William (2004), reported that the soil of Siwa contains many salts in the surface layers, especially sodium and magnesium salts which is a result of the flood irrigation using the underground water with its high concentration of salts, in addition to the high evaporation rate. This has a clear effect on the agriculture by damaging roots and reducing agricultural productivity.

Richards (1954), defined five soil salinity classes from non-saline soil to extremely saline soils. According to Richard's classification, agriculture soils of Siwa ranged from non-saline to highly saline (0.2 mS/cm to 10.7 mS/cm in spring, 0.3 mS/cm to 15.4 mS/cm in summer). In spring two stands (7 and 41) recorded highly saline soil, and in summer five stands (52, 53, 63, 64 and 66) recorded highly saline soil. Results of exchangeable ions showed higher concentrations in summer in comparison to spring. This may be due to the increase of evaporation rate in summer due to high temperature. Tizro and Voudouris (2007), mentioned that high rates of evaporation should lead to salt accumulation in the unsaturated zone, which can be dissolved by infiltrating water. Zahran (1972) revealed that the soil of Siwa consists of relatively large amount of soluble salts. The amount of sodium chloride contained in Siwa soils is at wide range from 0.12% to 59.12%. These results are in accordance with the present study. Field work showed that salts can accumulate on the surface layer to compose a layer of pure salt or to compose a solid surface layer of salt and clay mixture (called *karshaif* in Berber language of Siwa) which is used in the construction of the old houses and touristic places in Siwa Oasis.

On the other side and may be due to the less saline conditions, foliage projective cover, bare soil, nitrite and pH values were higher in the west of Siwa in comparison to the eastern sector and the old city of Shali. Correlation between shade and bare soil is clear in the light of the fact that shade (or light availability) is one of the restrictive factors affecting the density and diversity of the vegetation cover.

The old city of Shali soil analyses results showed a medium range between the eastern and western part of Siwa oasis for all soil parameters except for the organic carbon and matter, nitrate and phosphorus which may be due to the fact that this is the oldest part of Siwa and consequently it is the most productive part. Holding the highest prices over all arable lands of Siwa Oasis is a clear reflectance of this point. Organic carbon and matter play a crucial role in soil fertility (Abd El-Ghani, 1998). It varies considerably with locality and agricultural practices. According to Emerson (1991) and Charman and Roper (2007) classifications, most studied stands in spring had high organic carbon (more than 3%) on the other hand, about 89% of the studied stands in summer recorded low organic carbon content (less than 1%), organic matter was very low in summer than in spring as well . This might be due to the fact that farmers tend to leave their fields without cultivation in summer to avoid high temperatures and high evapotranspiration rates and the scarcity of water resources. These results are in accordance with (Mahsob, 1992).

Species assemblages

Siwa Oasis cultivation is composed mainly of palm and olive trees (>85%) in addition to some cash crops and fruit trees (Agricultural Administration of Siwa Oasis, 2015). Due to the high variability in soil properties, plantations and water quality, it is not unexpected to have a high variation in vegetation density and diversity.

Species richness of the studied stands was generally higher in spring than in summer because of the harsh summer conditions.

Species diversity and evenness were higher in palm groves than in the croplands and this may be due to many probable reasons. Firstly, high anthropogenic activity in the croplands to primate the main crop and suppress less competitive species (Mohler and Liebman 1987). Secondly, the plantation method of palms in which a space between palms is left empty in many cases allows two different situations inside the same patch to exist. Hegazy *et. al.*, (2004) found similar results comparing sunny and shady patches and vegetation inside citrus plantations

Data classification and ordination analyses used to identify species assemblages of Siwa Oasis agro ecosystems and its relation to different environmental factors have resulted in the separation of four ecological groups in spring and four ecological groups in summer. Each group has its unique indicator species that characterizes each group in addition to the environmental factors connected to this group.

Group 1. High salinity group

First ecological group was the salty group in spring and summer season. *Juncus rigidus, Tamarix nilotica* and *Arthrocnemum macrostachyum* were the indicator species of this group and it was represented by only 4 stands in spring and 15 stands in summer due to all the unfavorable conditions that enforce the accumulation of salts in soil. This group is positively correlated with all salt indicators including T.D.S, E.C, Mg^{++}, Ca^{++}, Na^{+}, K^{+} and Cl^{-} in both spring and summer seasons. Salinity is a major problem for arable lands in Siwa Oasis and in many arid and semi-arid regions globally (Munns and Tester, 2008; Zahran and Willis, 2009; Satir and Berberoglu, 2016; Gorji *et al.*, 2017 and Niñerola *et al.*, 2017). Under future climate projections, this problem is expected to escalate as temperatures rise and evaporation exacerbates water shortages. *Phoenix dactylifera* is a halo-tolerant species that could stand a wide range of salinity (Abd El-Ghani, 1994), however, in some locations in Siwa Oasis where soil and water were extremely saline, stands of palm trees were dying (Fig. 7).

In spite of the destructive effect of salinity on agriculture, it offers several opportunities at the same time. Many studies have discussed the use of halophytes as economic crops to be used as a replacement of the traditional plantations in saline arable lands (Neagu and Meana, 2013). Flowers and Colmer (2008) have defined halophytes to be the species able to survive and complete their life cycle under at least 200mM Na cl. Flowers *et al.* (2010) has indicated that halophytes can easily survive salinity conditions higher than seawater salt concentration. Usages of such plants include the consumption of these species as food for humans and livestock, in addition to the production of fiber and edible oils and as a source of energy (biodiesel and bioethanol) and some are considered ornamentals. Secondary metabolites of such species has medicinal, cosmetic, culinary properties. They could be also used as phyto-remediators for rehabilitation of degraded lands (Flowers *et al.*, 2010).

Indicator species of this cluster are widely distributed all over Siwa Oasis, not only inside the salt affected patches of agriculture but also in the non-cultivated saline lands. *Arthrocnemum macrostachyum* has been identified as a source of a healthy edible oil (seed oil content ranged from 22% to 25%) with 65% of unsaturated fatty acids, out of which 97% linoleic acid, and as a biofuel as well (Weber *et al.*, 2007). El-Shaer and El-Morsy (2008) reported that *Juncus rigidus*, an euhalophyte species, could be planted in saline soils as an unorthodox crop to produce mats and high quality paper; It could be also used in drug and oil industry in addition to its ability to be used as a phyto-desalinator species. *Tamarix nilotica* is a wide ecological amplitude species that dominates abandoned lands and can tolerate the harsh conditions of drought and salinity stress. It is not unusual to have roots over 50 m long to reach the underground water (Baum, 1978) and a salt accumulating species at the same time. It is also an important source of firewood and coal (Kassas and Girgis, 1970).

Group 2. High fertility group

The second ecological group had *Melilotus indicus*, *Malva parviflora* and *Eruca sativa* as indicator species, and was represented by 15 stands in spring. In summer, *Corchorus olitorius, Portulaca oleracea, Setaria verticillata* and *Chenopodium murale* were the characteristic species of this group, which was represented by 18 stands. This group is positively correlated with soil fertility indicators including organic carbon, organic matter, carbonates, bicarbonates, phosphorus, moisture content and clay content. *Chenopodium murale* is a worldwide invasive weed species that infests 25 crops in 57 countries (Holm *et al.*, 1997). The broader environmental adaptability and higher growth rate of *C. murale* is the main reasons of the successful invasion of this weed, in addition to its ability to stand different forms of phytotoxicity (Holm *et al.*, 1997 and Guertin, 2003). It affects the growth and nodulation of some crops by producing phenolic acids in the soil causing stress that is accompanied by reduction in water soluble proteins and carbohydrates and escalation of proline levels (Batish *et al.,* 2007).

Melilotus indicus is a wide ecological amplitude and a nitrogen fixative species (Zahran, 1998) that can germinate and grow under salt stress (Al Sherif, 2009). The ability to produce high nodulation percentage and nitrogenase activity make it an economically important species that should be used in soil fertility enhancement (Al Sherif, 2009). The salt inclusion mechanism of the *M. indicus* (Ashraf *et al.,* 1994) and the superiority over some halophytes as *Spergularia marina* in tolerating salt stress recommends its use as a soil ameliorator and as a fodder crop as well(Al Sherif, 2009).

Group 3. Sandy stands (Crop lands)

The third ecological group had *Medicago sativa, Chenopodium album, Convolvulus arvensis* and *Imperata cylindrica* as indicator species, and was represented by 27 stands in spring, while in summer *Medicago sativa, Cynodon dactylon* and *Convolvulus arvensis* were the characteristic species of this group, and it was represented by 22 stands. This group was correlated with sulfates, fine sand, very fine sand, calcium, chlorides and alpha diversity *Medicago sativa* is a perennial species that enhance soil fertility (Campiglia *et al.,* 1999). It can stand drought stress and it has a deeper root system that might help in accessing water (Volaire, 2008; Annicchiarico *et al.,* 2010). *Medicago sativa* is widely cultivated in Siwa oasis. It is the third after palms and olives to be cultivated in Siwa with 3000 feddans (13%) as it tolerates wide range of conditions and farmers need to plant it once every few years. *Chenopodium album* is an invasive annual herb that can tolerate a wide range of environmental conditions (Pearcy *et al.,* 1981). *Chenopodium album* tolerates Cu and Zn toxicity (Marschner, 1995 and Chino *et al.,* 1997) and could be employed as an indicator species for the presence of Zn and Mn (Walker *et al.*, 2004).

Group 4. Shady stands (Palm orchards)

The fourth group had *Lolium perenne* and *Sonchus oleraceus* as the characteristic species in spring, and it was represented by 18 stands. In summer, *Alhagi graecorum, Convolvulus arvensis* and *Cynodon dactylon* were the characteristic species of this group that was represented by eight stands. This group was correlated with foliage projective cover, bare soil, Beta diversity, species evenness, nitrates and pH. *Lolium perenne* is a salt tolerant species that has a strong ability to protect itself against zinc toxicity. *Sonchus oleraceous* is a wide spread weed that is used as an antimalarial in Africa. It can occur in a wide range of well drained soils but it cannot stand water stress (Shaltout, 1994 and Holm *et al.*, 1997). Alhagi is a nitrogen fixative species (Zahran, 1998) that might be used as an indicator of soil water level (El-Bana and Al-Mathnani, 2009).

Conclusion

This study has revealed that the classification and distribution of Siwa Oasis agro ecosystems and its flora is based on several elements: 1) Salinity: including water and soil salinity 2) Plantation: whether the stand is an orchard or an open field (including what species of crops or trees is/are planted) 3) Shade: whether the stand is shady or sunny or a mixed patches of shade and sun 4) Water availability as a limiting factor (including water logging and drought stress) 5) Anthropogenic activity: whether the stand is heavily impacted by anthropogenic activity or not (this contains all forms of human intervention including the application of pesticides and fertilizers).

These factors interact to produce a diversity of vegetation assemblages comprised of native species, agricultural weeds and economic crops. These assemblages are not static, but change over time in response to seasonal, biotic and human factors. Rising salinity due to long-term agricultural practices presents the major problem economically, socially and ecologically into the future. Research should be directed towards assisting farmers to adapt to drier and/or saltier soils with appropriate land and water management strategies, including selection of crops, methods of irrigation and identifying suitable areas for cropping.

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Appendix. List of the environmental parameters, indicator and characteristic species of Siwa Oasis arable lands and its abbreviations. For the complete list of Species refer to (El-Saied, 2015).

Species	**Abbreviation**	**Environmental**	**Abbreviation**
Alhagi graecorum	Alh gra	Alpha diversity	Alp div
Apium nodiflorum	Api nod	Altitude	Altit
Arthrocnemum macrostachyum	Art mac	Bare soil	bare land
Bacopa monnieri	Bac mon	Bicarbonates	HCO3
Brassica rapa	Bra rap	Calcium	Ca
Chenopodium murale	Che mur	Carbonates	CO3
Chenopodium album	Che alb	Chlorides	CL
Convolvulus arvensis	Con arv	Clay	Clay
Corchorus olitorius	Cor oli	Coarse sand	C. sand
Cynanchum acutum	Cyn acu	Evenness	Eveness
Cynodon dactylon	Cyn dac	Fine sand	F.sand
Cyperus rotundus	Cyp rot	Foliage projective cover	Shadow
Eruca sativa	Eru sat	Gravel	Gravel
Ficus carica	Fic car	Magnesium	Mg
Imperata cylindrica	Imp cyl	Nitrate	NO2
Juncus rigidus	Jun rig	Nitrite	NO3
Lolium perenne	Lol per	Organic carbon	Organic ca
Malva parviflora	Mal par	Organic matter	Organic ma
Medicago sativa	Med sat	Phosphorus	P
Melilotus indicus	Mel ind	Potassium	K
Mentha longifolia	Men lon	Shannon index	Shanon Index
Olea europaea	Ole eur	Silt	Silt
Phoenix dactylifera	Pho dac	Sodium	Na
Phragmites australis	Phr aus	Electrical conductivity	E.C.
Portulaca oleracea	Por ole	Moisture content	moi con
Punica granatum	Pun gra	pH	pH
Ruppia cirrhosa	Rup cir	Sulphates	so4
Samolus valerandi	Sam val	Total dissolved salts	T.D.S.
Setaria verticillata	Set ver	Very Fine sand	V.F.snd
Silybum marianum	Sil mar		
Sonchus oleraceus	Son ole		
Tamarix nilotica	Tam nil		