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OXALIS CORNICULATA AS A SUCCESSFUL LAWN WEED: A STUDY OF MORPHOLOGICAL VARIATION FROM CONTRASTING HABITATS

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Abstract

Oxalis corniculata, an abnoxious weed and is of cosmopolitan distribution. The species is a successful invader and seems to be adapted to a wide array of habitats. In the present study various survival strategies of the species under different environmental conditions were assessed through the variability of morphological character expressions. Eight populations of the *O. corniculta* were sampled from 4 contrasting habitats and were studied for various traits. The populations exhibited distinct morphological responses with respect to changing environmental conditions. The variability of phenotypic expressions seems to provide some selective advantage for survival under contrasting habitat situations. The species appeared to be a successful lawn weed as the maximum adaptive significance of character expressions was observed from a mowed lawn. The study suggested that various abiotic/ biotic factors did not limit the growth of the species. Hence, chemical control seems to be an appropriate strategy for weed management.

Introduction

The term 'weed' is used for a number of species that are invasive plants of natural and agricultural ecosystems (Charudattan, 2005). Weeds are regarded as a nuisance because they are unwanted plant species. Weeds interfere with human land use as they are successful colonizers and have considerable impact on plant growth (Garbari & Pedulla, 2001). Weeds also cause problems for water management as they impede flow of water through irrigation ditches. Weeds are well adapted to highly unstable and unpredictable environments as they can compete with plants for nutrients, water, light, space, and harbor crop pests or diseases through different survival tactics (Rodenburg *et al.*, 2010).

Morphological variation leads to different survival strategies has long been recognized because it enables the plants to acclimatize in changing habitats (Gambino & Vilela, 2011). Phenotypic variability is a reflection of the genetic constitution of the individuals and their interaction with the environment. Thus, morphological expressions are usually pertinent to habitat conditions (Jaleel *et al*., 2008; Mandák *et al*., 2011). Hence, plant populations occupy and are maintained in diverse habitats through the adjustment of morphological expressions (Urbas & Zobel, 2000).

O. corniculata or creeping wood-sorrel, or yellow wood-sorrel is of cosmopolitan distribution and is considered as a troublesome weed that successfully grows in lawns, arable lands, waste places and gardens. It tends to become especially troublesome in pots growing in greenhouses (Anon., 2000).

Although, the traditional approach to study weeds is to examine their control or management (Rodenburg *et al*., 2010) but the main goal of weed management is to understand the way by which weeds exist? Therefore, in the present study several populations of *O. corniculata* were studied from contrasting habitats. These provenances were examined for various phenotypic expressions to understand the survival strategies and successful invasion of the weed in a wide range of habitat. Thus, the main objectives of the study were to reveal population differentiation in *O. corniculata* from contrasting environments as well as to explore the variability of morphological expressions that provide some selective advantage to the species for its maintenance in a variety of habitat.

Materials and Methods

Choice of sites: Several sites at Bahauddin Zakariya University Multan, Pakistan (30°11N and 71°28E) were visited to observe natural growing populations of *O. corniculata.* The species was found growing under different environmental conditions. Four contrasting habitats (8 sites) were selected for sampling. The sampling details are summarized in Table 1.

Table 1. Habitats types and description of the sites selected for sampling of populations of *Oxalis corniculata.*

S. No.	Habitats	Description
1.	Sun	An open area with maximum exposure to sun light, high temperature, rain fed area.
2.	Shade	With thick canopy of *Accacia nilotica*, *Morus nigra* and *Eucalyptus lanceolatum* with greater amount of litter.
3.	Irrigated area	Along a water course, highly moist soil.
4.	Derelict/ Dry land	Dry sandy soil, rain fed area with harsh set of environmental conditions.
5.	Neighboring with grasses	Lawn of Botanic Garden with different grass species *Poa annua, Dicanthium annulatum, Polypogon monspeliensis, Cyprus rotendus, Cynodon dactylon,* competition for space, water, light nutrients etc.
6.	Neighboring with Shrubs	Growing in competition with Shrubs like *Dodonia viscosa*, *Rosa indica, Hibiscus rosasinensis, Nerium oleander.* Soil sandy loam, competition for water and nutrients, low light intensity due to shade of shrubs.
7.	Mowed Lawn	A well maintained lawn. Regular mowing with ample watering.
8.	Unmowed site	Flower beds of a lawn with some annual ornamental plants such as *Bellis perennis, Helianthus annuus, Petunia alba, Lathyrus odoratus* and *Tagetes erecta.*

Sampling: Ten plants each regarded as an individual of the species were sampled from each habitat from an area of 20m^2. Each individual plant was taken by keeping at least 2 m distance between them to obtain a genet. The plants were carefully uprooted and placed in paper bags. They were brought back to the laboratory for morphometric analysis.

Character choice and biometric analysis: Early observation has revealed that *Oxalis corniculata* is variable for various morphological expressions. Choice of character expressions was made for vegetative and reproductive traits. Overall eight characters (root length, number of branches per plant, petiole length, leaflet length and width, leaf diameter, pedicle length and fruit length) were selected for morphometric analysis, and consistent measurements were taken from all 10 plants.

Statistical analysis: Mean values for each attribute and standard errors were calculated using MS Excel, 2000. In order to reveal significant differences between habitats and individuals a two way analysis of variance (ANOVA) was carried out using MS Excel, 2007. Thus, morphological variability within and between habitats was elucidated. Least Significant Differences (LSD) were calculated by Duncan's Multiple Range Test (Duncans, 1955) at 5% level of probability.

Results

Root length: The results as mean values for root length (Table 2) revealed that the root lengths vary considerably in plants from various habitats. The maximum root length (9.45cm) was observed under sun while, the lowest root length (3.04cm) was noticed for plants growing under irrigated conditions and differ significantly from all other habitats. However, no significant differences were observed in plants that were taken from other sites. Analysis of variance (Table 3) could not reveal significant variability within population but different habitat conditions had a significant influence on the root length of the species.

Table 2. Overall mean values (± S.E) for various biometric characters in populations of *Oxalis corniculata* sampled from contrasting habitats during spring season.

Characters	Habitats							
	Sun	Shade	Irrigated area	Derelict/ Dry land	Neighboring with grasses	Neighboring with shrubs	Mowed lawn	Unmowed site
Root length	9.45± 0.83c	7.33 ± 0.53b	3.04 ±0.72a	7.12 ±0.25b	4.37±0.43b	6.21±0.46b	5.12±0.37b	7.58±0.7b
Number of branches	5.3±0.33d	2.4±0.22a	4.4 ±0.27c	3.00± 0.26b	3.5±0.31b	4.8±0.39c	6.6± 0.59e	2.00±0.26a
Petiole length	8.09±0.39g	7.24± 0.2f	7.09± 0.24e	3.62± 0.28a	3.52±0.21a	5.73± 0.23c	4.93±0.32b	6.44±0.39d
Leaflet length	1.75± 0.06f	1.9 ± 0.04g	1.64 ±0.05e	1.13± 0.14b	0.9±0.03a	1.36± 0.05d	0.91± 0.05a	1.3±0.03c
Leaflet width	2.3±0.08f	2.3 ±0.06f	2.19±0.07e	2.39±0.07g	1.36±0.03b	1.9±0.09d	1.34±0.06a	1.73±0.04c
Leaf diameter	3.51±0.13d	3.86±0.12e	3.29±0.1d	2.01±0.12b	1.97±0.05a	2.74±0.12c	1.93±0.07a	2.68±0.08c
Pedicel length	5.76±0.96f	4.6±0.29e	5.56±0.53f	3.86±0.4a	4.1±0.15c	4.34±0.22d	3.72 ±0.24a	4.00 ±0.24b
Fruit length	1.88±0.05e	1.77±0.06d	1.61±0.03c	1.35±0.06a	1.57±0.07c	1.81±0.04d	1.47±0.04b	1.5±0.03b

Each mean value is across five replicates/ individuals and across ten individuals/ Habitat. Mean values in each row sharing same letter do not differ significantly by Duncan Multiple range Test at 5% probability level.

Table 3. Summary of Analysis of Variance for various biometric characters in populations of *Oxalis corniculata* sampled from contrasting habitats during spring season.

Characters	Individuals			Habitats			Interaction		
	MS	F	Significance	MS	F	Significance	MS	F	Significance
Root length	38.33	1.41	N.S	290.43	13.82	***	38.33	1.41	N.S
Number of branches	10.25	0.98	N.S	170.60	20.98	***	10.25	0.98	N.S
Petiole length	42.21	5.26	***	982.64	157.35	***	250.05	4.44	***
Leaflet length	1.63	1.23	N.S	49.47	48.08	***	15.25	1.64	**
Leaflet width	3.88	13.38	***	66.20	93.04	***	12.33	6.07	***
Leaf diameter	6.89	13.47	***	195.62	491.48	***	33.86	9.45	***
Pedicel length	54.95	2.36	*	826.40	8.30	***	554.25	3.40	***
Fruit length	3.09	4.15	***	11.55	9.92	***	7.91	1.51	**

MS=Mean Squares , N.S=Non significant and *, **, *** = Significant at 0.05, 0.01 and 0.001 levels of probability, respectively.

Number of branches per plant: Mean values for number of branches per plant (Table 2) depicted a significant variation for this attribute from various habitats. The individuals that were growing with lawn grasses exhibited the greatest number of branches (6.6). Similarly, the individual plants growing under full sun had greater number of branches (5.3) and the two habitats differed significantly. However, the lowest number of branches (2) was counted for those plants that were collected from flowering beds. Likewise, plants from shaded habitat also had lower number of branches (2.4) and were significantly variable from other habitats. Analysis of variance presented in (Table 3) depicted no significant variability between individuals of the same habitat. However, the individuals from contrasting sites showed significant variation for this parameter.

Petiole length: It is obvious from Table 2 that plants exposed to full sun exhibited the maximum petiole length (8.09cm) while, the lowest petiole length (3.52cm) was observed for plants, which were growing among other grass species but did not differ significantly from the shorter petioles of dry land plants. However, the petiole morphology varied significantly among plants of all other habitats. Statistical analysis of the data (Table 3) revealed a significant contrast among various habitats. It is also evident from the Table 3 that individuals also showed considerable dissimilarity for petiole length. Consequently, individual × habitat interaction was found to be statistically significant.

Leaflet length: Data for leaflet length presented in (Table 2) revealed the most elongated leaflets (1.90cm) in plants of a shady habitat and showed a remarkable contrast from other habitats. The plants from a well-irrigated site and those, which were collected from a sunny location, also had greater length of the leaflets (1.36-1.75cm). The lowest leaflet length was observed for plants that were growing among grasses (0.90cm) and lawns (0.91cm) but did not show any variability between them. It is also evident from the analysis of variance (Table 3) that there was significant contrast between different habitats for leaflet morphology. However, the individuals from similar sites exhibited no significant variability for this attribute. The Table 3 also depicted a significant individual × habitat interaction.

Leaflet width: Leaflet width in plants from contrasting habitats varied considerably (Table 2). The pattern of variability was comparable to leaf let length as the maximum leaflet width 2.39cm was recorded for plants growing under full shade. Higher mean values were also observed for plants growing in an open sun 2.3cm and under moist conditions 2.19 cm. However, the minimum leaflet width 1.34 cm was noticed for plants that were taken from a lawn. Similarly, the plants growing with other species 1.36 cm and dry habitat also had lower 1.39 cm leaflet width. The data clearly depicted significant differences between mean leaflet widths form contrasting sites except from sunny and shaded sites. Statistical analysis of the data (Table 3) revealed marked differences within population and between populations as well as significant individual × habitat interaction.

Leaf diameter: The results as mean values for leaf diameter (Table 2) exhibited a significant dissimilarity for leaf diameter of plants from different habitats. The greatest leaf diameter was observed for the individual that were growing in full shade 3.86 cm. Plants sampled from an open sun site and those, which were growing on a well-irrigated site, also showed greater leaf diameter 3.51-3.29cm but no significant difference were observed for these two habitats. Plants that were growing with other plant species had smaller diameter of leaves 1.97-1.93cm, though the two habitats did not showed any significant variation between them. Similarly, significant reduction in leaf diameter was also noticed in plants of a dry habitat and had a significant distinction from all other habitats. The analysis of variance (Table 3) depicted that individual plants differ significantly. Likewise, various habitat conditions had a significant influence on leaf diameter and a significant individual × habitat interaction was also observed.

Pedicle length: The maximum pedicle length 5.76 & 5.56 mm was observed for plants that were growing in full sun and moist conditions, respectively but no significant difference were observed between them. The shorter pedicle was recorded for plants growing in lawn 3.72mm and under dry conditions 3.86mm but they were significantly invariable. However, plants from all other habitats showed a considerable variation for this attribute. Marked differences within and between populations were observed and a highly significant interaction is also evident (Table 3).

Fruit length: Table 2 indicated that the maximum fruit length 1.88cm was observed for the plants growing in full sun. Similarly, individual plants exhibited greater fruit length when growing under shady condition and with shrubs. However, the fruit length was insignificantly variable between these two habitats. The lowest fruit length 1.35cm was observed for plants growing under dry conditions and differed significantly from all other habitats. Statistical analysis of the data presented in (Table 3) depicted significant variability both for the individual plants and habitats. Moreover, the individual × habitat interaction was also significant.

Discussion

This work considered the differentiation of morphological responses of *O. corniculata* collected from several contrasting environmental situations. Natural growing populations of the species had shown a significant variability for a number of morphological expressions under contrasting habitat conditions. Thus, the species seems to possess a wide range of phenotypic variability for both vegetative and reproductive traits. The phenotypic variation results not only from morphological and physiological characters but also emerged from the interaction of a particular developmental plan, the genotype with a particular environment (Bellavance & Brisson, 2010). Thus two types of morphological expressions were studied because certain traits are more liable to change, thus phenotypically more variable (vegetative characters) while, floral and fruiting characters are considered to be genetically controlled (Navas & Garnier, 2002).

The variability of morphological characters is also pertinent to habitat conditions. Changing environmental conditions are reflected by plant phenotypes having variable morphology of plant modules. The populations growing under similar habitat conditions may show comparable morphological expressions. Moreover, the differentiation of various morphological characters in the field may occur due to the variability of environment and have an evolutionary implication that results in the gradual adaptation of the species to different environmental situations (Mahmood & Abbas, 2003; Hussain & Mahmood, 2004). Therefore, morphological variability studied for various characters in populations is described here in relation to their adaptive significance to habitat conditions.

Root is an important organ that not only anchors the plants to soil but plays a critical role in the absorption of water and mineral nutrients. The development of root may influence over all development of plant. Modification of root morphology can be related to different survival strategies in a variety of habitats. The results of the study clearly indicated that root length varied significantly under contrasting habitat conditions. The stronger root system was observed for the plants growing under full sun because temperature increase has a direct effect on soil moisture content. Under water deficit conditions longer roots have a selective advantage for efficient water and mineral absorption to support luxurious plant growth. However, root growth was not profound under irrigated conditions. The plants growing under xeric conditions have well developed root system for efficient water absorption (Zhu *et al.*, 2011, Zhang et. al., 2004) and the species also showed a similar strategy. Thus, from this study adaptive morphology of the root growth can be established in a water deficit environment.

The study revealed a significant variation for the number of branches per plant. The number of branches was lower in the light deficient environment while, the maximum number of branches was observed in the mowed lawns. The extensive branching system in response to mowing disturbance seems to provide better survival to the species as there will be less chances of plant maintenance with fewer branches after mowing. Hence, the species showed more rigorous growth in a disturbed environment. Field observations have also revealed prostate growth habit of plants rather than erect forms in mowed lawn. Again this variability has some adaptive role as erect individuals are more prone to mowing regime. The lowest number of branches and erect individuals were observed from flower beds where mowing was absent. These results are in close agreement with (Reisch & Poschlod, 2011) who reported similar pattern of differentiation in *Scabiosa columbaria* from a mowed lawn and adjacent flower beds.

The leaf is an important photosynthetic module that assimilates carbon. Several changes in the leaf morphology and physiology were reported for a number of other plant species where contrasting habitats had significant influence on leaf characters (Fila & Sartorato, 2011; Burghardt *et al*., 2008). Various leaf attributes; leaflet length, leaflet width and leaf diameter varied considerably under different habitat conditions. The most expanded leaflets were observed for the plants under shade that presumably evolved to perceive more light in a less illuminated environment. Whereas, an overall reduction of leaflet length and width was observed for the plants growing in mowed lawns. Again this might has given a selective advantage to the species as mowing/ disturbance regime was avoided through the reduction in leaflet diameter because more expanded leaflets are more vulnerable to mowing. In addition, smaller leaflets under dry conditions may play a role in maintaining water economy under a moisture deficit environment (Geng *et al.,* 2006). An affirmative relationship was observed for leaflet length and width and for leaflet width and leaf diameter.

The study clearly showed that petiole length varies remarkably under varying environmental conditions. The smallest petioles were observed when plants were growing in mowed lawns and under dry conditions. In both habitats reduction in petiole length might have given plants a successful approach for survival to avoid mowing as well as less elevated leaf surfaces to reduce transpiration. Petioles were regarded as the most plastic organs **(**González & Gianoli, 2004) and our results also support the findings of above workers.

The results reported here indicated significant morphological variability for pedicle and fruit length in relation to variable habitat situations and a significant contrast between populations was observed for these expressions. Although these attributes are genetically determined but can subject to selection. Mandák *et al.*, 2011 argued that superior pod morphology (dry conditions and mowed lawn) may allow populations better chances of survival and competitive ability. Moreover, two theories have been put forth regarding the survival of individuals in a wide range of habitat by MacArthur and Wilson, 1967. Within an environment where the habitat conditions are erratic, *r*-selection favors those individuals, which produce large number of progeny. Conversely, in a crowded habitat, *k*-selection favors those individuals, which have superior progenies. Though, there was less competition in dry habitat but limited soil moisture may restrict fruit development. Similarly, the populations from lawn and flower beds were in competition with plant species but fruit progeny did not excelled for its size (*k*-selection). Thus any resilience to wide array of environmental conditions through the selection of fruiting traits was not affirmed from this study.

This study clearly demonstrated that populations of *O. corniculata* have responded differentially to various environmental conditions. A significant differentiation for various morphological characters became evident. The species became well adapted to various habitat conditions through the variability of various traits. Therefore, maintenance of the populations under contrasting environment presumably depends on the alteration of phenotypic variation for both vegetative and reproductive traits.

Conclusion

It can be concluded from the study that *O. corniculata* had shown local population differentiation. Each population had distinct morphology in relation to habitat conditions. The provenances seem to be adapted to various environments through the modification of morphological characters. The altered morphology might have given some resilience to the species to maintain itself under contrasting environmental regimes. The species appeared to cope with light deficient environment through the modification of leaf. Since, large sized plants can be more vulnerable to mowing and cutting therefore, mowing damage was avoided by the reduction in plant height, growth habit and foliar architecture. Modification of these characters thus had allowed the species to endure itself in lawns and consequently eradication of weed becomes more difficult. For this reason, the species is considered as a troublesome lawn weed because of its changing morphology which gives its superior ability to survive. Similarly, reduction in overall transpiring surfaces in dry habitat also has an adaptive significance to maintain water economy. The population from an open ground exhibited well developed individuals because all nutritional and light requirements seem to be fulfilled (long roots and more developed leaf branches). The study indicated that each character has an independent pattern of differentiation for vegetative and reproductive traits. The modification of certain traits in a particular set of environmental conditions may allow the species a better survival and maintenance ability. The study clearly suggested that each population of the weed is well adapted to its habitat. The maximum modification of traits was observed in a mowed lawn because of characteristic survival strategy. Based on these results it can safely be concluded that *O. corniculata* successfully invades lawns and is difficult to eradicate. Thus, chemical control seems to be an appropriate tool for the management of this weed.

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