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Responses of Two Rangeland Noxious Plants Species to a Seasonal Drought

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ABSTRACT

Aims Drought and high temperatures are main environmental stresses for noxious plants in the arid environments. Responses of arid land plants to drought are complicated and include different adaptive mechanisms in terms of physiological, morphological, and phenological responses. This research aimed at investigating phenological and/or morphological responses of two globally important noxious plant species, *Centaurea virgata* Lam, and *Scariola orientalis* (Boiss.) Soják, during growth season of a dry year.

Materials & Methods The present experimental research site was conducted in Noh-Dareh Mountains, Mashhad, Iran. Weekly field visits were done during the growth season (March to September) in 2011. Understory soil moisture and air temperature were recorded together with some morphological plant traits of both species. Daily air temperature and sporadic rainfalls were recorded and their possible effects on changes in plant phenology were investigated. The data were analyzed by SPSS 22 software, using t-test to examine differences in the selected parameters between the two species at each phenological stage.

Findings Both species produced temporal rosette leaves that favored the high soil moisture in early growth season (March) and led to rapid shoot (stems and cauline leaves) production in the late April. However, they showed contrasting growth strategies in response to rain pulses and summer drought.

Conclusion *C. virgata* is a drought escaping and opportunistic plant that threats the native flora during spring of normal and wet years, whereas *S. orientalis* is a slow growing drought resistant species and can be a major treat both in dry and normal years.

Keywords *Centaurea virgate*; *Scariola orientalis*; Morphology; Seasonal Responses; Phenology

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Introduction

Noxious species are major threats to biodiversity and ecosystem stability [1]. Knowledge of the responses of noxious plants to the environmental severities is useful for their control. Noxious plants may show several strong or weak responses to the environmental stresses, especially in their natural habitats [2].

Drought and high temperatures are the main environmental stresses for noxious plants in the arid environments. Responses of arid land plants to drought are so complicated and include different adaptive mechanisms in terms of physiological, morphological, and phenological responses [3].

Drought avoidant plants respond to drought mainly by coordinating their phenological growth stages with the variations in soil moisture. In contrast, drought tolerant species may withstand drought periods via physiological and/or morphological adaptations that enable them to conduct photosynthesis under drought conditions [4].

Phenology of plant species can change in response to the seasonal changes in the environmental variables such as air and soil temperatures, precipitation, soil moisture, and nutrient. Changes in plant phenology can be regarded as an efficient mechanism to cope with stressful conditions [5] and climate changes [6]. For example, in dry years, drought avoidant plants may terminate their life cycle earlier. Many studies have shown drastic effects of air temperature and precipitation on the timing of plants development [7, 8].

Morphological and physiological responses to high temperature and drought are also important plant strategies that allow plants to avoid or tolerate water stress. For instance, resistant plants are equipped with morphological, anatomical, and physiological plasticity that enable them to tolerate dehydration under drought conditions [9]. Furthermore, reductions in plant growth, total plant leaf area, specific leaf area, and leaf number have been reported as major responses to the drought [10, 11].

In the arid and semi-arid ecosystems, occasional rain pulses lead to the temporal nutrient pulses. Such pulses of water and nutrient provide a limited opportunity for plants to take up resources and increase their growth [12]. Invasive plants have adapted to such conditions by acquiring several morphological and physiological traits that maximize pulse water use. They may show small root, shoot ratio, predominantly shallow root system, and maximal leaf conductance with high stomatal sensitivity to plant water potential [13] and acquire a greater ability to benefit nutrients and compete with native species [14].

Centaurea virgata Lam. and *Scariola orientalis* (Boiss.) Soják are two invasive plant species that usually grow in the marginal lands and disturbed rangelands of Iran and worldwide [15, 16]. A seasonal drought in spring and summer 2011 provided an opportunity to study their responses to drought and high temperature. Although the two species have similar growth form and ecological function (invasive) in semi-arid rangelands, they may respond differently to drought stress and sporadic rainfalls in terms of phenology and shoot morphology.

We studied changes in phenological stages (vegetative, flowering, and seed ripening) and morphological traits (number of leaves, leaf, and stem length) in relation with the gradual changes in soil moisture, near surface air temperature, and sporadic rain pulses during a single growth season.

Results of this study can be used to control these invasive plants and predict their responses to the future climate changes.

This research was conducted with the aim of comparing responses of two globally important noxious plants to summer drought, in a dry year.

Material and Methods

Study site: This experimental research was performed in Noh-Dareh Mountains, Southwest of Mashhad, Iran. Altitude varies from 1056 to 1334m above the sea level and geographic coordinates are 36° 17´48" to 36° 17' 50" E. and 59° 28´29 to 59° 28´30 N., respectively. Climate is semi-arid with the long-time (50 years) average annual rainfall being 246mm [17]. The site is a natural rangeland, which had been under sever livestock grazing for decades; however, during last 15 years, it has been included as part of the urban county of Mashhad (Khorshid Park), and, hence, livestock grazing is prohibited. Physical disturbance may happen at some parts of the site due to mountain walking and probable road constructions. Weather data were obtained from Torogh weather station for 10 years

(2000-2010), about 10km far from the study site, which included daily data on rainfall and average of monthly data on air temperature.

Plant species: *C. virgata* is a perennial forb with maximum height of 20-70cm and severely branched shoots. Flowers are red or purple and fruits are achene [15]. *S. orientalis* is a perennial forb with frequent dens stems that has light-gray color with green ribbons on the surface. Its total height reaches 15-50cm, flowers look pale yellow, and fruits are achene [16].

Sampling and phenological studies: Data recording started at the beginning of growth season, in mid-March 2011 and continued till early September 2011. Sampling was done in a randomized-systematic method, in which transect places were chosen systematically, but plant individuals were randomly selected along each transect. Two belt transects (50m length, 5m wide) were established in 20m distances, on one of the southern slope aspects of No-Dareh Mountains. Five individuals of each species (*C. virgate* and *S. orientalis*) were randomly selected along each transect. Individual plants of similar size and apparent high vigor, growing under similar micro-topography conditions were selected.

Study on the phenological stages was performed once every 2 weeks and continued till the end of growing season. For each plant, the exact time of phenological events i.e. leaf emergence, early and full vegetative growth, early and full flowering, seed producing, seed ripening, and leaf shedding were recorded.

Microclimate features: In each phenological stage, soil moisture was measured under canopy of each plant at depth of 10cm by a portable digital soil moisture meter model MP M160 (ICT International; Australia). Also, soil temperature was similarly measured by conventional digital thermometer.

Plant morphological traits: Stem length and number and leaf length and number were measured in 20 selected individuals of *C. virgata* and *S. orientalis*, 7 times within the growing season.

Leaf relative water content (LRWC): At each selected stage of growth and development, leaf samples were taken from same plants randomly, packed in plastic bags, and transported on wet ice to the laboratory. Weatherly method [18] was used for measuring LRWC.

Root system study: Belt transect method was used to sample the selected species. Root depth and its distribution area were measured in 5 individuals of each species at the flowering stage. Soil profiles were dug out (30-70cm deep) and root systems of 5 plants of the selected species were taken out for further analysis.

Statistical analysis: Relationships of environmental factors (soil moisture and temperature) and plant morphological traits (leaf number and length, stem number, and length) were investigated. The data were analyzed by SPSS 22 software, using Independent t-test to examine differences in the selected parameters between the two species at each phenological stage.

Findings

Impact of microclimate conditions on phenology: Compared with the averages of air temperature and precipitation in last 10 years, a dry growing season in 2011 (2000-2010) was observed (Diagram 1). The general trend in the seasonal changes of air temperature in 2011 was similar to the past 10 years. Nevertheless, the average of the highest monthly air temperature during the 2000-2010 was around 25°C in July, but it was 27°C in August in 2011. For both cases, the least monthly air temperature was about 3°C in January. There were significant differences between the rainfall trends in 2011 and the previous 10 years for the early months (March-May) of growing season. In April 2011, when both *C. virgata* and *S. orientalis* were at the full vegetative stage, the mean of monthly precipitation was 12mm, whereas it was 44mm during the previous decade, indicating severe drought season in spring 2011 (Diagram 1). The total precipitation in growth season (March-August) was about 50% lower in 2011 than the average past 10 years. Therefore, both *C. virgata* and *S. orientalis* should have experienced the intense drought condition during their growth period in 2011.

There were some coincidences between phenological stages of *C. virgata* and that of *S. orientalis* with daily changes in temperature and precipitation during the growing season of 2011 (Diagram 2). Zero time in the diagrams was set on 9th of February. For both species, emergence of the first leaves was associated with an increase in daily maximum and minimum air temperatures in early March. A precipitation event was coincident only with the emergence time of *S. orientalis.*

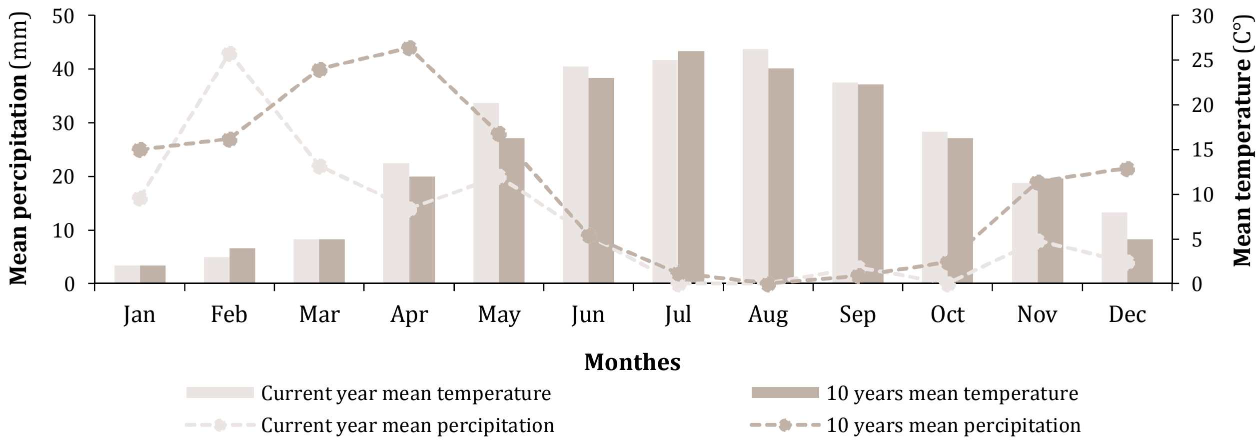

Diagram 1) Comparing monthly changes in mean temperature and precipitation between the year of study (current, 2011) and average of previous 10 years

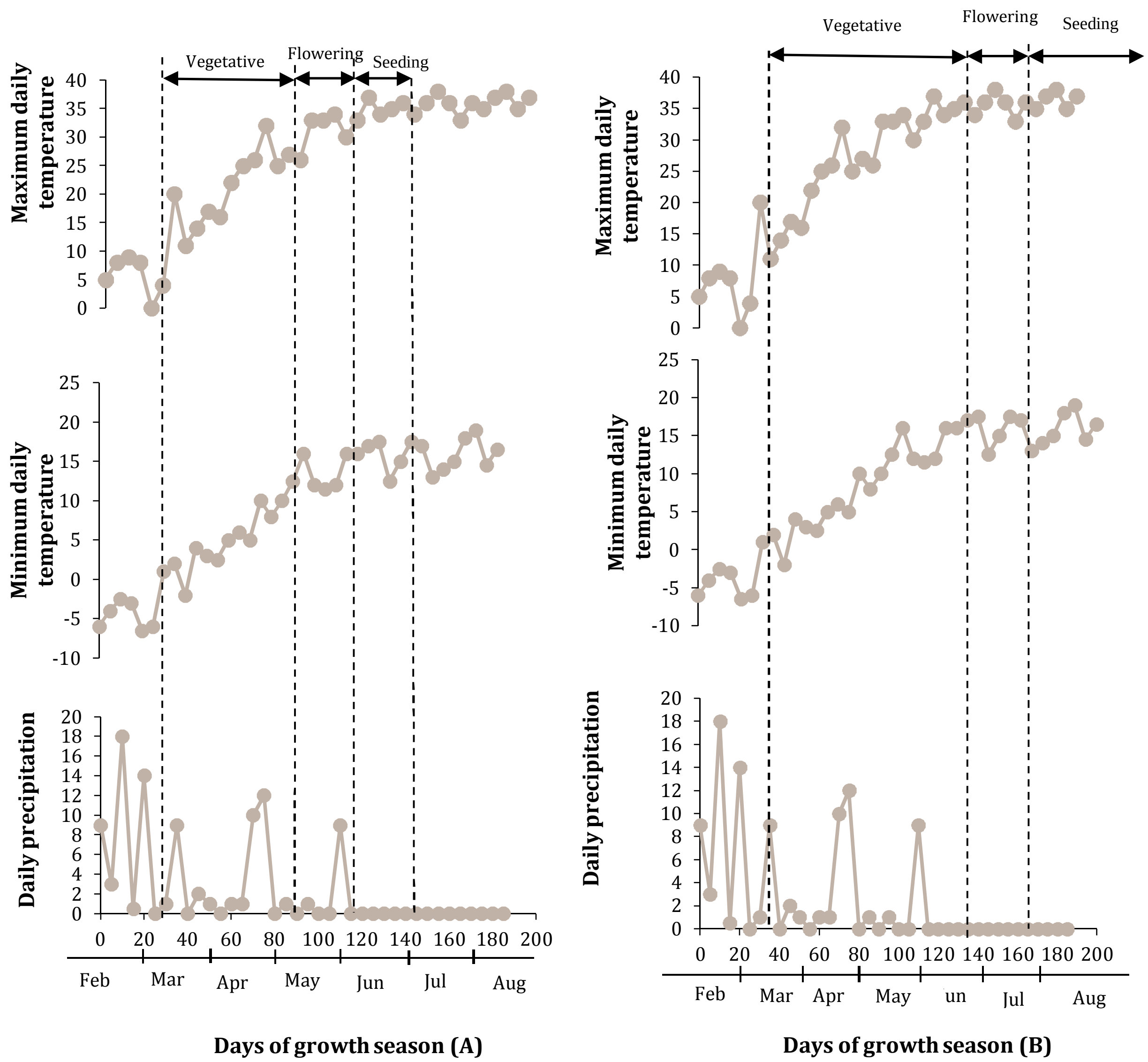

Diagram 2) Changes in phenology of *C. virgata* (A) and *S. orientalis* (B) in relation to daily changes (precipitation, minimum, and maximum temperature) in air temperature and rainfall during the growing season of 2011

Soil moisture under the canopy of both studied species was at the maximum level in mid-March and diminished ($p<0.05$) from March till the end of the growing season in August. In this regard, no significant difference was found between *C. virgata* and *S. orientalis* at the selected phenological phases (Diagram 3A).

For both species, the minimum soil temperature around the roots was recorded in early April, and significantly increased ($p<0.05$) till mid-May, after which, soil temperature remained stable till the end of the growing season. Soil temperature under plant canopy was significantly different between the two species only at days 25, 40, and 65 after the beginning of vegetative growth ($p<0.05$). Flowering stage of *C. virgata* occurred at lower temperature and higher soil moisture than those of *S. orientalis* (Diagram 3B).

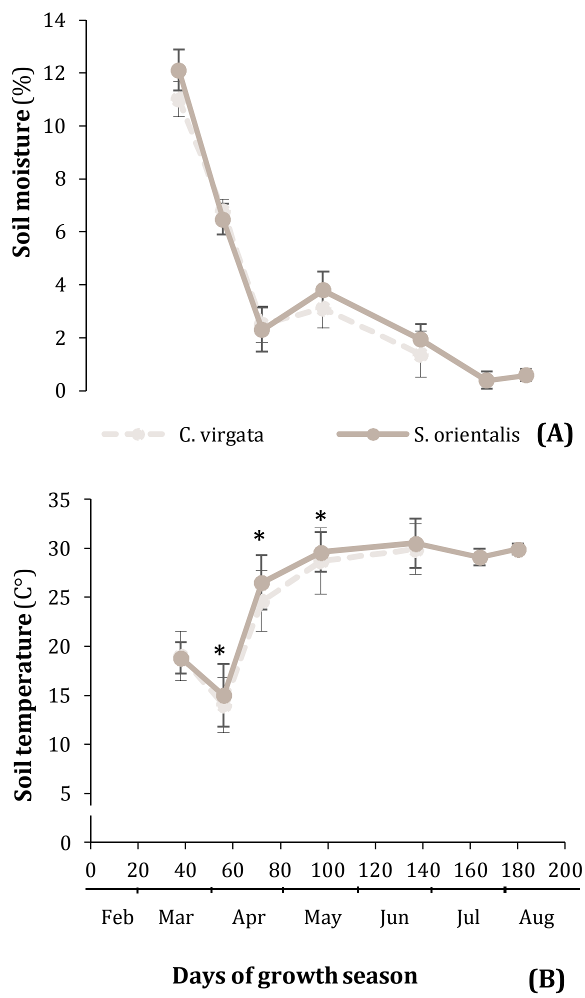

Diagram 3) Soil moisture (A) and temperature (B) changes in the root media of *C. virgata* and *S. orientalis* during growing season. Error bars are shown for each data; significant difference between mean data of two species is shown by an asterisk (*)

LRWC of *C. virgata* did not vary during vegetative and flowering stages (from mid-March to early June), but it significantly decreased at the seed bearing stage (late June; $p<0.05$). *S. orientalis* showed a sharp and significant reduction in the LRWC going forward to complete its phenophases at seed ripening stage ($p<0.05$; Diagrams 2 and 4). Both species had significant differences in the LRWC throughout the whole growth season ($p<0.05$; Diagram 4).

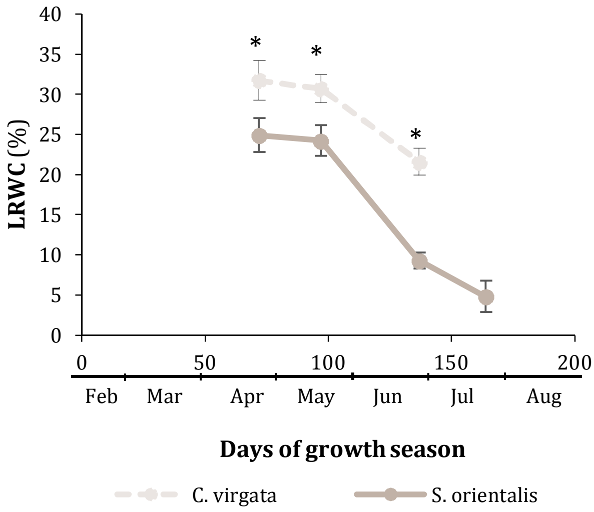

Diagram 4) Leaf Relative Water Content (LRWC) changes in *C. virgata* and *S. orientalis* during growing season. Error bars are shown for each data; significant difference between mean data of two species is shown by an asterisk (*)

Changes in plant morphology during growth period: There was a significant difference between the morphology of two species over 180 days in terms of stem number and length ($p<0.05$; Diagram 5). Both *C. virgata* and *S. orientalis* started the early growth by producing rosette leaves at mid-March. Stems developed about 30 days later, when the rosette leaves had already died. For both species, a significant and rapid increase in stem length and number started from day 60 of the growing season (early April; $p<0.05$). In *C. virgata*, increase of stem length continued till late June; however, in *S. orientalis*, it reached to a maximum height in early May and remained constant till mid-August (Diagram 5A). Similarly, stem number increased until early May and mid-April in *C. virgata* and *S. orientalis*, respectively (Diagram 5B). On mid-May and late June (90 and 130 days after the beginning of growing season), *C. virgata* had more stems than those of *S. orientalis.*

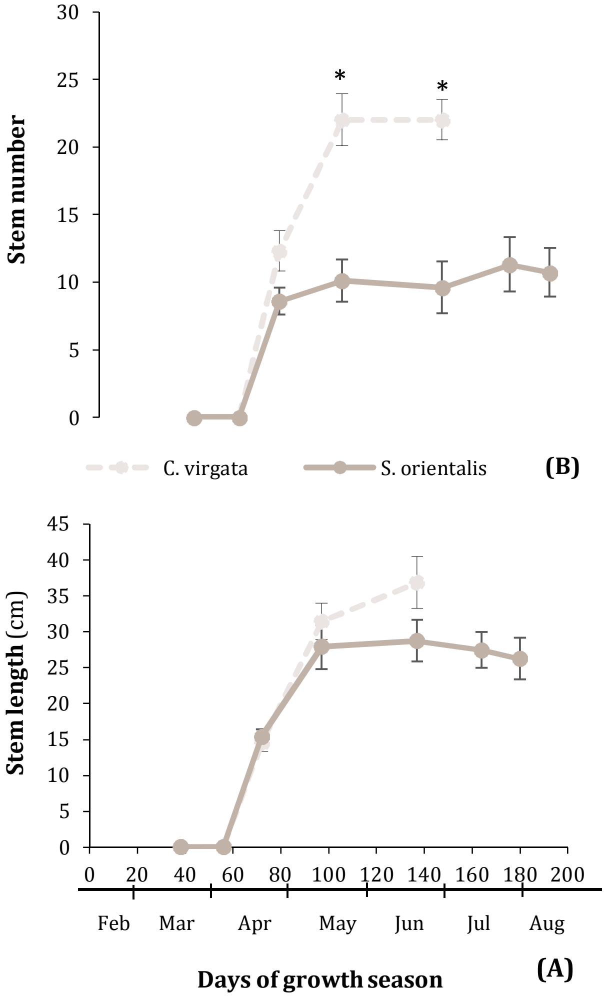

Diagram 5) Stem length (A) and number (B) changes in *C. virgata* and *S. orientalis* during growing season. Error bars are shown for each data; significant difference between mean data of two species is shown by an asterisk (*)

Enhancement of the leaf length during mid-March till early April was followed by a progressive decrement by late August (Diagram 6A). A sharp decrease in leaf length was due to the death of rosette leaves for both species, which was concurrent with considerable reduction of soil moisture. In mid-May, a remarkable difference in leaf length was observed between two species ($p<0.05$). In *C. virgata*, the number of leaves increased till early flowering stage (mid-May) and went into decline; such a change was significant only in April ($p<0.05$). Also, in *S. orientalis*, the number of leaves per plant rapidly declined from late April to mid-May, so that at the end of the vegetative stage, there was almost no leaf on the stems (Diagram 6B). Moreover, *C. virgata* had higher leaf number than *S. orientalis* through all stages of its life cycle (from early April until late June).

The mean root length of *S. orientalis* was much longer than that of *C. virgata*. Average root depth penetration for *C. virgata* was about 30cm, but in *S. orientalis*, it continued below the large boulders (>70cm). Because of rocky substrate, we could not record the maximum root penetration depth for *S. orientalis*.

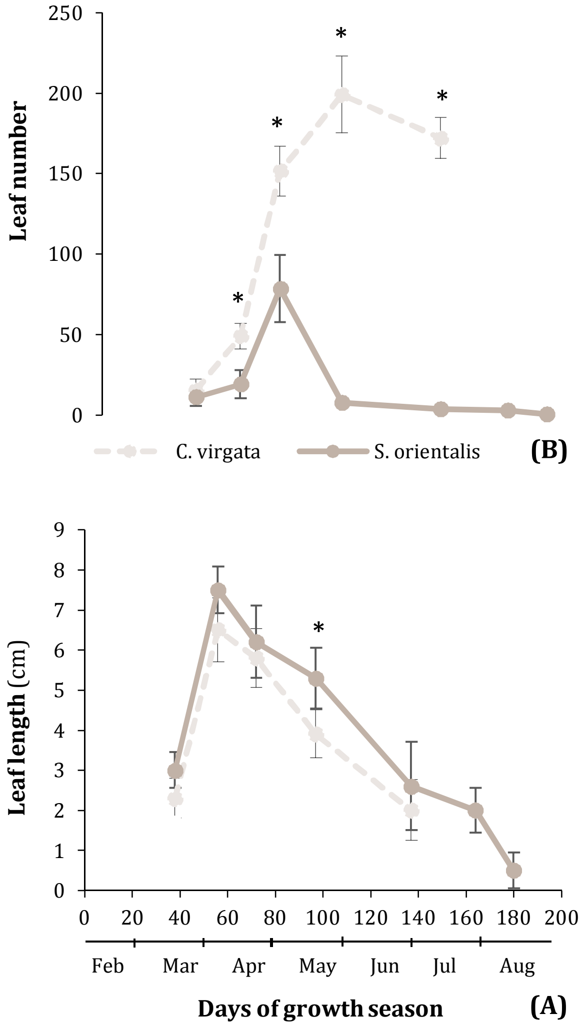

Diagram 6) Leaf length (A) and number (B) changes in *C. virgata* and *S. orientalis* during growing season. Error bars are shown for each data; significant difference between mean data of two species is shown by an asterisk (*)

Discussion

As two invasive species in arid and semi-arid regions, *C. virgata* and *S. orientalis* are adapted to temporal changes in rain pulses and soil moisture during a dry growing season. For both invasive species of this study, rosette leaves are great tools to benefit the favorable growth conditions and rain pulses in early growing season. However, as drought stress intensified from mid-June, it significantly affected morphology and phenology of both species. *Centaurea virgata* as a drought escaping species responded to low water stress by shedding leaves, speeding up the flowering stage, and shortening life cycle, while drought tolerant *S. orientalis* could withstand summer months by shedding leaves, relying on photosynthetic stems and using water from deeper soil layers.

Both *C. virgata* and *S. orientalis* favored mild air temperature and high soil moisture in early spring. Their early emergence happened after a sudden increase in the air temperature at mid-March. Environmental factors can significantly affect plant phenology. Among these factors, air temperature has a great impact on the time of occurring phenological phases. The vegetative growth of *C. virgata* and *S. orientalis* began in March 11th and March 16th, respectively, after a sudden increase in air temperature.

Previous studies have shown phenological responses to increase air temperature, e.g. of 243 studied plant species in England [19] or 78% of 542 plant species in 21 European countries [20].

In the arid and semi-arid ecosystems, sporadic rain pulses lead to the soil moisture pulses and higher nutrient uptake [21]. Nevertheless, plant responses to the water and nutrient pulses are highly dependent on their root systems [22]. According to this study, *C. virgata* can be more dependent on the pulses because of having a shallow root system. Its growth and development were strongly influenced by the amount of daily precipitation and rain pulses. There was a direct relationship among the changes in the soil microclimate conditions (i.e. soil moisture and temperature), the changes in the timing, and duration of *C. virgata* phenophases. On the other hand, deep root system in *S. orientalis* allowed higher access to the deep soil moisture, and, hence, lower dependency of phenological stages to the rain pulses in the growing season.

In this research, both *C. virgata* and *S. orientalis* showed adaptive responses for the higher use of favorable microclimate conditions (soil moisture and temperature) in the early growing season and avoiding drought stress during the summer. For *C. virgata,* flowering and seeding stages started shortly after the occurrence of rain pulses and relative decrease in air temperature in mid-May and early June, respectively. However, *S. orientalis* started and completed its flowering and seeding phases in dry season when precipitation had already stopped.

The changes in phenology is an effective mechanism to cope with drought stress [23]. Water shortage can also be a limiting factor for plant growth and development in arid and semi-arid ecosystems with extreme effect on plant phenology [24]. Autumn flowering of *Globularia alypum* and *Erica multiflora* was more dependent on water availability than on temperature [25]. Two *Rubus idaeus* cultivars showed earlier flowering, a shorter fruit production period and earlier senescence under drought conditions [26]. Sometimes, simultaneous increase of air temperature and drought intensity can change the timing of phenological events and shorten the duration of certain plant phenophases [27]. In alpine cushion plants, flowering improved by increasing temperatures and decreasing soil moisture due to microclimate changes [28].

In the present study, some morphological plant traits were measured during growth season. For both species, stem growth was stopped with increasing temperature and decreasing soil moisture content. However, it happened earlier in *S. orientalis*. Earlier stem growth stop in this species can be considered as a sign of higher adaptation to the stressful environmental conditions [29]. Water stress usually leads to stomatal closure, reduced transpiration rates, decrease in gas exchange, decrease in photosynthesis, and, finally, growth inhibition [30]. Also, plant growth is inhibited by reduction of cell division and cell expansion in response to cell dehydration [31].

Adaptive responses of both species can also be tracked by comparing the changes in leaf length and number (total photosynthetic surface area) of two invasive species during the growing season. Basal (rosette) leaves were produced for a higher use of rain pulses in the early growing season. The basal leaves are important structures for fast growing perennial plants [32]. For both *C. virgata* and *S. orientalis*, basal leaves were replaced with new stems and branches by increasing temperature and intensity of solar radiation in late spring till end of summer.

Under drought condition, the length and number of leaves declined for both species. In *S. orientalis*, the decrease of leaf number and in *C.*

virgate, the decrease of leaf size was pronounced, while *S. orientalis* could tolerate the heat and dehydration period mostly by reducing the transpiration rate through the losing leaves. This species had green photosynthetic stems, which may help it to keep up the rate of photosynthesis and continue growth during the summer drought. Leaf growth termination, leaf shedding, and general reduction in the transpiration rate are adaptive mechanisms that help plants to survive under the dehydration conditions [33].

Occurrence and benefit of stem photosynthesis along with leaf shedding is a good evidence about the crucial role of this alternative photosynthetic organ to improve plant water use efficiency (WUE) and continue carbon fixation after shedding under drought stress [34]. One reason for reducing the number of leaves in both species, especially in *S. orientalis*, can be leaf shedding due to the stimulation of enzymatic activities such as cellulase and polygalacturonase in response to the reduction of LRWC [35]. The leaf relative water content of both species reduced from the beginning towards the end of the growing season; a greater reduction for *S. orientalis* was due to its longer growth period during summer heat and drought. Other researchers have also found the decline in LRWC, leaf length, and number in plants under drought stress [36, 33].

Monitoring gradual reduction of soil moisture around plant roots could represent more detailed information on adaptation of noxious plants to use rain pulses and drought tolerance. Therefore, for future studies, we suggest comparing simultaneous changes in soil moisture around roots of noxious plants and their companion native forage species, at different times after a rain pulse or in different times of a growth season. It would be more interesting if the changes in soil moisture is related to physiological conditions (i.e. stomatal conductance, assimilation rate) and plant water status (leaf water potential).

Conclusion

C. virgata is a drought escaping and opportunistic plant that threats the native flora during spring of normal and wet years, whereas *S. orientalis* is a slow growing drought resistant species and can be a major treat both in dry and normal years.

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