Perspectives on the relationship between invisibility, richness, plant size, seed production, seed bank and community productivity of invasive *Argemone ochroleuca* Sweet in Taif, Saudi Arabia

Sanaa, A. I. Moussa

Botany Department, Faculty of Science, Cairo University, Giza, Egypt
Present Address: Girl's Faculty of Science, Biology Department, King Abdulaziz University, Jeddah, KSA
sanaa_moussa1958@yahoo.com

Abstract: *Argemone ochroleuca* Sweet is an invasive desert weed species; a worldwide medicinal plant with economic potentialities. It is recently introduced ,in Saudi Arabia especially in Taif Governorate. The later is one of the largest areas, in the Southeastern of K.S.A. characteristic by its high diversity in local climatic and topographic conditions. Dryness is a characteristic climatic feature of the area since rainfall is less than 10 inches and a maximum temperature of 37^0C are reached in September. Temperature decreases the dryness in the angle of rain and evaporation, thus it affects the vegetation of the area . The large widespread of the species due to its high propagation ability encourages the studying of the inter-relationship between its invisibility and some of the biological characteristic features such as species richness of its communities, average plant size, seed production ability and *Argemone* stored seeds (number of seeds contained.$m^{-2}$of surface soil). Some of the chemical characters of the soil such as the organic matter content as well as the variations in topographic features of the different habitats could be main reasons for the variations in species productivity in the different habitats. Nine localities representing three different habitats; sand plains, dams& wadies were selected. *Argemone ochroleuca* is highly reproducible invasive desert weed; it produces a huge average number of 189 capsules, with a maximal number (258) at Al-Shafa and a minimal (162) at Jabajeb. An average number of 453 seeds per capsule- with a higher value (473) at Al-Shafa- was counted. An overall average number of 85, 850 seeds per individual were obtained. The immense number of seeds evinces the high propagation of the species. *A. ochroleuca* tends to inhabit the less fertile soil and reduces the native plant diversity in Taif. *A.* seeds stored in superficial soil (seed bank; SB) attained an average value of 7, 736. m^{-2}; the highest (13,600) at Jabajeb. Species richness; SR, was negatively correlated with invisibility (INV). The later was positively correlated with both plant size (PS) and seed production (SP), while negatively correlated with SR & SB. PS was positively correlated with INV and SR. A negative correlation was also between SR and all other variables. PS was negatively correlated with either SR or SB.

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1. Introduction

A. mexicana is a principal weed of beans and maize in Tanzania, cereals in Australia and India, cotton in Nicaragua, potatoes in India, tobacco in Argentina and Puerto Rico, and wheat in Pakistan (Holm *et al.,* 1977). It grows as a common weed in many crop fields such as, sugarcane, potato, tea, tomato and bean (*Phaseolus vulgaris*). It reduces the wheat grain yield (Rawson& Bath, 1980) as its seed is an undesirable contaminant in grain sold for seed or stock food, in turn; a high level of control is required. *A. mexicana* has an inhibitory effect on germination and seedling growth of vegetables (Hazarika & Sannigrahi, 2001) and weed residues may affect Bambara groundnut (*Vigna subterranea*) and sorghum (*Sorghum bicolor*) growth and development because of the inhibitory effects of allelochemicals present (Karikari *et al*. 2000). Grazing animals generally avoid this weed but can be poisoned if it is consumed in hay or chaff. The value of wool is decreased when contaminated by the prickly fruits of *A. mexicana* (Parsons & Cuthbertson, 1992). Harvesting by hand of low-growing field crops can be a painful experience in the presence of *A. mexicana*. Ownbey (2007) differentiates *A. ochroleuca* from *A. mexicana* on the basis of differences in flower bud shape and petal colour. Seedlings are readily controlled by light tillage. Long cultivated fallow or vigorous perennial pastures will control large infestations (Parsons and Cuthbertson, 1992). *A. mexicana* is an invasive weed of different aged soil dumps (Kumar *et al.,* 2011) and there is an increament in vegetation diversity as man precedes towards the upper aged soil dumps. Herbicides which control *A. mexicana* include 2, 4-D, 2, 4-DB, dicamba, diuron, fluroxypyr, hexazinone, isoproturon, karbutilate, MCPA, metribuzin, oxadiazon, picloram and terbutryn. A biological control programme of *A. mexicana* and of closely related *A. ochroleuca* has been initiated in Australia. This native of Mexico is naturalized in most warm countries of the world in sub-humid as well as semiarid regions.

Invasive species are one of the most significant threats to native species diversity, and identifying the factors that make places more or less invasible has been one of the most important issues in the study of invasions (Wilcove *et al.,* 1998; Pimentel *et al.,* 2000). From a theoretical perspective, the reasons some communities are more invasible than others is a question intrigue ecologists (Cadotte *et al.,* 2009) because it underlines fundamental concepts in community ecology: species coexistence and assembly (Tilman, 2004). Serpentine systems attributed this behavior to the often extreme environment within these communities. Spatial heterogeneity, spatial scale (local or regional) and productivity are critical elements in understanding the invasibility of communities. Harrison& Cornell (2008) studied richness at either local or regional scales. Starzomski *et al.,* (2008) found that local richness did not depend on regional richness during any time of community assembly. Elton (1958) first proposed that a high richness of native species armors sites against invasion by making reasons less available to newly arriving species. Many studies supported this idea by detecting negative relationships between native and exotic diversity at small spatial scale – the scale of interaction between individuals - (Brown& Peet, 2003). Later authors revealed that competition from resident species has strong and significant effects on both establishment and performance of invaders. Native and exotic diversity could positively correlated only on larger spatial scale and furthermore the most diverse regions are often the most invaded, particularly for plant communities (Harrison *et al.,* 2006). Davis *et al.,* (2007) demonstrated that the relationship between native and exotic diversity flipped from negative to positive at scales at which spatial heterogeneity in the environment came into play.

The history of introduction of *A. mexicana,* now occupying large tracts of deteriorated rangelands in Asir region, KSA is not traceable. *A. ochroleuca* was most widespread in Taif area (Shorbaji & Abidin, 1999). The two species are growing in almost all types of soil and at different climatic conditions. In addition, all stages of growth can be observed in the same area at the same time of the year. Studies showed that noxious weeds also decrease wildlife forage quality (Medina, 1998) essentially needed by livestock. Therefore, determining *Argemone*'s rangeland distribution and its invasion ecology are essential for planning control measures of this weed. Recently, Moussa *et al.,* (2012) studied the vegetation in the different habitats in Taif, KSA and explained that the selected localities are of moderately diversed native 35 species belonging to 25 different families; the largest of which is Compositae. They added that *Argemone* has the highest importance value.

2. Materials and Methods:

During the year 2008/09 vegetation study of *Argemone ochroleuca* was undertaken in nine selected localities in Taif Governorate, KSA (Moussa *et al.* 2012) that lies in the desert and semi-desert region of the world. These localities represent different habitats that varied from: sand plains (as in Al-Shafa; 25 km Southwest of Taif, Jabajeb; Northwest of Taif& Al-Arafah; 35 km North of Taif), dams (as in Gadeer; 7 km South of Taif& Ekrima; 6 km Northwest of Taif) and wadies (such as in Thumalah & Wadi S,ab; 25& 5 km Southwest of Taif, respectively, Saysid and Jaleel; 14& 28 km Northwest of Taif, successively). Vegetation was studied in order to cover all vegetation variations in all directions around Taif and the importance value of the species - that represents the invisibility - was calculated. Richness as a measure of the species diversity (Pielou, 1975; Magurran, 1988) as well as the average *Argemone* plant size was estimated for the different localities. *Argemone* productivity tests (average number of flower buds, flowers& fruits per individual plant as well as the average number of seeds per fruit) were calculated. Finally, the average number of seeds produced per individual was estimated at all selected localities. Soil samples (five replications, 0.25 m^2 each) from the underneath of the plants were superficially collected, intermixed, air-dried then re-divided for homogeneity. Percentage of organic matter content (Walkley& Black, 1934) as well as organic carbon content (Page *et al.,* 1982), was estimated. Seed trapping activities determines the quality of invasive species arriving at each locality. So, seed bank (the number of *Argemone* seeds stored.m^{-2} soil) was evaluated using five replications of 5 g soil samples. Separation took place by the floating method using 40 % $CaCl_2$ and examination took place using an electric binocular (X 20). Because *Argemone sp.* has a tendency to multiply rapidly thereby choking the land to compete with other range plant species and reduce the land value, the variation between community parameters (invisibility; INV, species richness; SR, plant size; PS, seed production; SP, *Argemone* seed bank; SB& soil organic matter content as a measure for community productivity; OM& OC) in relation to the different localities was assessed using One-Way analysis of variance (ANOVA). Species richness as a measure of species diversity was calculated as the average number of species recorded in each locality. Relationships between community variables and each other were tested using simple linear correlation coefficient (*r*). The statistical package SPSS version 10.0 for windows was used for different statistical analyses..

3. Results and Discussion:

Argemone ochroleuca is an invasive worldwide medicinal plant with economic potentialities. *A. mexicana* is adapted to a wide range of habitats, including humid and semi-arid areas and a wide range of soil types. It occurs as a weed of arable land, pastures and in waste places, roadsides and fence rows. In East Africa it is reported in grasslands and savannas (Lyons& Schwartz, 2001). It is known from sea level to elevations of 2900 m in Tanzania (Holm *et al*., 1977). Taif is the largest city in KSA, distinguishing by a strategic site. It lies between East and Southwest of KSA. It is also characterized by its mountainous topography and mild climate. The first documentation of the genus in Saudi Arabia was given by Migahid (1974). Hussein *et al.* (1983) found *A. mexicana* in different investigated desert areas in KSA. Currently, the two species were already identified in the same country (Collenete, 1985; Chaudhary & Al-Jowaid, 1999). *A. mexicana* now occupies large tracts in deteriorated rangelands in Asir region. *A. ochroleuca* is most widespread in Taif Governorate (Shorbaji & Abidin, 1999). Both species are distributed in the western and southern parts of the Kingdom, the former being unintentionally introduced from the New World. In the present study, nine locations in Taif representing different habitats; sand plains (open areas), dams and wadies were selected to detect hazardous role of *Argemone* as an invasive weed. Recently, vegetation strategies were studied at the same localities in Taif, KSA (Moussa *et al.,* 2012).

Fig. 1. *Argemone Mexicana*

Table (1): Productivity tests of *Argemone ochroleuca* plants at the different localities.

Locality	Av. no. of flower buds / indiv.	Av. no. of flower / indiv.	Av. no. of fruits / indiv.	Av. no. of seeds / fruit	Av. no. of seeds / indiv.
Al-Shafa	21	12	258	472.7	122,160
Jabajeb	18	12	162	435.5	70,515
Al-Arafah	20	10	223	460.7	102,558
Gadeer	20	16	163	463.3	75,438
Ekrima	20	16	215	440.1	94,708
Thumalah	19	12	170	466.9	79,185
Wadi S'ab	22	11	164	433.0	71,188
Saysid	16	16	167	447.0	74,644
Jaleel	18	14	179	458.6	82,257
Mean value	19.3	13.2	189	453.1	85,850

A. ochroleuca is a highly reproducible invasive desert weed (Table 1). By the end of 2009, estimates of the species productivity revealed that the number of flower buds ranged from a lowest value of 16 (in Saysid locality) to a highest of 22 (in Wadi S˒ab locality) per individual plant. Meantime, the number of produced flowers ranged from 10 (as a lowest value in Al-Arafah locality) to 16 (a highest value, simultaneously monitored in Gadeer, Ekrima& Saysid localities). The species produces huge numbers of fruits that ranged from a lowest of 162 (at Jabajeb) to a highest of 258 per individual (at Al-Shafa). The later locality was also distinguished by giving a maximized number of 473 seeds per fruit whereas a minimal number of 433 seeds was given at Wadi S˒ab locality. So an overall maximal number of 122,160 seeds per individual *Argemone* plant were rained at Al-Shafa locality while a minimal overall number of 70,515 seeds were detected at Jabajeb. It was observed that seeds produced in large quantities tend to fall near the parent plant producing dense stands. The plant is known to break off at the base and be windblown for long distances helping to disperse seeds. The immense numbers of produced seeds evinces the high propagation of the species. Seed production of *Argemone* varies throughout the world. Mauritius reports the greatest seed production with an average of 60 to 90 capsules per plant with 300 to 400 seeds in each capsule (Holm *et al.,* 1977). They added that most seeds fall around the base of the parent plant where they form a carpet of seedlings. Dispersal occurs in surface water and in mud adhering to farm machinery and the feet of man and livestock. Seeds are readily eaten by a number of bird species in Puerto Rico as indicated by the presence of many seeds of the species in birds' stomachs (Barnés, 1946). In Ethiopia, most seeds do not normally germinate the year after shedding. Instead they enter the seed bank and seedlings establish, even in well-maintained field, probably for many years (Karlsson *et al.*, 2003). Number of seeds buried in superficial soil layer (seed bank of the species) attained a mean value of 7, 7 36. m^{-2} that ranged from a minimal value of 3,000 at Ekrima (dam topographic habitat) to a maximal value of 13,600 at Jabajeb (an open sand plain habitat). An intermediate mean value of 7, 275 seeds was recorded in wadies of Thumalah, S˒ab, Saysid and Jaleel. On raining, water is stored behind the dams that help in dispersing most of seeds on flooding, thus attaining the lowest seed bank values. The intermediate values found in wadi habitats might be a result of water runoff that carries seeds from the surrounding higher terraces and settles them down the wadies. The possession of maximized seed bank value by the sand plain topographic habitat ensures the intensive receive of seeds arriving by different dispersal means. Plant size (PS) varied at the studied localities; the largest of which (5.8 m^3) was detected at Al-Shafa, while the smallest (3.7 m^3) was distinctive at Gadeer. An average value (4.2 m^3) was recorded.

Along with spatial scale, site productivity likely affected the invisibility of communities and thus the relationship between native and exotic diversity, (Davis *et al.,* 2007) especially at small scales, where competitive exclusion potentially varied with site productivity. Authors continued that productive sites had a common positive relationship between native and exotic diversity, whereas unproductive sites had a common negative relationship. Generally, in Taif, *Argemone* tends to inhabit the less fertile (less productive) soils, having low organic matter and organic content (Table 2). Former parameter varied from a least value of 0.55 (at Al-Shafa) to a highest of 3.75 % (at Jabajeb) while the second one ranged between 0.24 (also at Jabajeb) and 1.67 % (at Al-Shafa). This comes in concordance with Parsons& Cuthbertson (1992) who mentioned that the species tends to grow best in soils of low fertility. They added that in Australia, it is peculiarly adapted to colonize derelict areas low in phosphorus. *A. mexicana* is better suited to grow at sites deficient in nitrogen whereas the closely related *A. ochroleuca* does better where phosphorus is limiting (Ramakrishnan & Gupta, 1972). Moussa *et al.* (2012) reported that slight alkalinities as well as complete lacking of carbonates are characteristic features for the studied localities. They added that high EC is expressed at Jaleel and owed that trend to the possession of higher contents of Ca^{+2}, Cl^- & SO_4^{+2}. They continued that highest Mg^{+2}content is detected at Ekrima, while Na^+ is exceedingly measured at Thumalah. Neither species appear to have obvious restriction to particular agronomic or environmental situations (Karlsson *et al*., 2003). In southern India it occurs up to an altitude of 800 m a.s.l. and when growing in undisturbed land, it can produce fresh weights of 6-9 t/ha but, in cultivated land, it is generally not an aggressive competitor (Holm *et al*., 1977).

Argemone invisibility (INV); expressed as the importance value; varied with the variation in localities. The highest invasibility (180) was detected at Al-Arafah, followed by 150 at Al-Shafa, while the lowest value (97) was recorded at Wadi S˒ab. The remaining localities attained intermediate values. Species richness showed negative correlation (Tables 2& 3) with the invisibility; as the former decreases with increasing the later and vice versa. To-date little is known about the impact of *Argemone* on biodiversity. Kumar and Rohatgi (1999) postulated that the species decreases biodiversity in India.

Community productivity; expressed as organic matter and organic carbon content (Table 2) was moderately detected (3.75& 1.67 %, respectively) at Jabajeb where the least species richness (2.6) was recognized. Hodgson *et al.* (2002) found a positive relationship between diversity and productivity and a negative diversity – invisibility, productivity – invisibility relationship among bacterial colonies.

One Way ANOVA test showed significant differences (F-ratio = 0.00; sign. =6.51, 22.09, 5.38& 34.99) between invisibility (INV), species richness (SR), plant size (PS) & seed bank (SB) values of the nine localities (Table 2). The highest value of invisibility (180±26.07) was found at Al-Arafah locality, while that of species richness (9.07±2.12) was attained at Gadeer. Al-Shafa was distinguished by possessing the largest plant size (5.72±0.76) as well as the highest seed productivity (122,160±11,258). Higher organic matter& organic carbon (3.75; 1.67%, respectively) were detected at Jabajeb.

The calculation of correlation coefficient (*r*) between the different community variables (Table 3) indicated that invasibility (INV), plant size (PS) & seed productivity (SP) had the highest number of correlations with high significant positive correlations between each other. Correlation between INV, SR, PS, SP& SB and each other (Table 3) indicated that INV positively correlated with both plant size (PS) & seed production (SP). Plant size (PS) positively correlated with invasibility (INV) & seed productivity (SP). The later (SP) positively correlated with invisibility (INV) & plant size (PS).On the other side, there was a negative correlation between INV, SR& SB. A negative correlation was also obtained between SR& all other variables and also between SP, SR& SB. Plant size (PS) also negatively correlated with seed bank (SB).

Table (2): Means of *Argemone* variables (±S.D) at the nine studied localities ; INV, Invisibility ; SR , Species Richness ; PS , Plant Size ; SP , Seed Productivity ; SB , Seed Bank ; OM, organic matter content; OC, organic carbon content; SD , Standard Deviation.

Argemone variables	Locations									Total ± SD		
	1	2	3	4	5	6	7	8	9		F-ratio	Sig.
INV (Invasibility)	150 ±32.37	120 ±17.13	180 ±26.07	101 ±15.64	138 ±17.16	110 ±22.23	97 ±36.63	109 ±20.64	120 ±10.61	125.0 ± 33.13	6.51	0.00**
SR (Species Richness)	3.07 ±0.96	2.60 ±2.31	4.07 ±1.28	9.07 ±2.12	7.13 ±2.23	7.73 ±1.87	6.20 ±2.51	7.20 ±2.08	7.93 ±1.39	6.11 ± 2.86	22.09	0.00**
PS (m^3) (Plant Size)	5.72 ±0.76	3.88 ±0.68	4.18 ±0.28	3.66 ±0.54	3.95 ±0.49	4.63 ±0.75	3.70 ±0.73	4.10 ±0.64	4.25 ±0.41	4.23 ± 0.82	5.38	0.00**
SP (seed/indiv.) (Seed Productivity)	122,160 ±11,258	70,516 ±19,935	102,558 ±13,540	75,439 ±11,585	94,708 ±17,184	79,185 ±17,228	71,189 ±14,887	74,644 ±17,105	82,257 ±36,720	85,851 ±41,108.	0.87	0.55 n.s
SB ($seed.m^{-2}$) (Seed Bank)	7,100 ±1,387	13,600 ±2,219	6,700 ±908	10,120 ±756	3,000 ±353	7,200 ±1,095	8,600 ±1,025	5,700 ±570	7,600 ±418	7,736 ± 2,978	34.99	0.00**
OM (%)	0.55	3.75	2.41	2.00	0.78	0.73	3.44	1.56	0.94	1.79		
OC (%)	0.24	1.67	1.07	0.89	0.35	0.33	1.53	0.70	0.42	0.80		

Numbers from 1-9 are the studied localities (1,Al-Shafa ; 2, Jabajeb ; 3, Al-Arafah ; 4, Gadeer ; 5, Ekrima ; 6, Thumalah ; 7, Wadi S'ab ; 8, Saysid ; 9, Jaleel; (**), significant at 1%.

Table (3): Pearson's - product moment correlation coefficient (*r*) between the estimated community variables. For variable abbreviations& units, see Table (2).

Variables					
INV.		-0.590	0.420	0.801**	-0.324
SR	-0.590		-0.404	-0.479	-0.274
PS	0.420	-0.404		0.778*	-0.225
SP	0.801**	-0.479	0.778*		-0.447
SB	-0.324	-0.274	-0.225	-0.447	
	INV	SR	PS	SP	SB

** Correlation is significant at the 0.01 level (2-tailed), * correlation is significant at the 0.05 level.

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