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ESTABLISHMENT, GROWTH AND PRODUCTIVITY OF SELECTED MEDICINAL PLANT SPECIES IN THE ARID ZONE 100-200 MM RAINFALL, IN JORDAN

JAMAL R. QASEM[1*], JAMAL S. SAWWAN[2] AND AHMAD K. AL-MATTARY[3]

[1]*Department of Plant Protection, Faculty of Agriculture, University of Jordan, Amman11942, Jordan*
[2, 3]*Department of Hiorticulture and Crop Sciences, Faculty of Agriculture, University of Jordan, Amman11942, Jordan*
[*]*Corresponding author's email: jrqasem@ju.edu.jo*

Abstract

Six field experiments were conducted at Al-Muwaqar (arid) and Al-Jubeiha (Mediterranean) locations, Jordan for four years to study establishment, growth and production of selected medicinal species under supplimentary irrigation, water harvesting and soil conditioner treatments. Results showed that 70% of plot area left for water harvesting significantly increased leaf number and total fresh and dry weights of *Salvia officinalis* L., *Rosmarinus officinalis* L. and *Origanum syriacum* L., compared with no water harvesting. The larger the water harvesting area the more growth obtained and up to 90% however, total yield remained lower than that of no water harvesting. Soil conditioner (polymer) at 300 g/m^2 significantly increased growth of all species and soil moisture content more than in water harvesting treatments. *R. officinalis* was best established, while water harvesting and soil conditioner were more beneficial to *O. syriacum* than other species. Studies on adaptability and survival of 15 medicinal plant species in Al-Muwaqar showed great variations in their performance and responses to irrigation. Although some appeared well adapted but their growth and productivity were better at Al-Jubeiha location. *Foeniculum vulgare* Mill, *Carthamus tinctorius* L., *Lepidium sativum* L. and *Cynara scolymus* L. tolerate Al-Muwaqar dry conditions, while *C. scolymus* was best established and yearly growing.

Key words: Medicinal plants, Arid conditions, Cultivation, Polymer, Water harvesting, Productivity.

Introduction

Al-Muwaqar area is characterized by low average and erratic rainfall, long hot dry summer, high solar radiation and evaporation rate, intensively poor-eroded soil because of different factors, among which are strong wind currents and running water erode fine soil particles (Abu-Irmaileh, 1987; Taimeh & Hattar, 2001). Overgrazing lead to absence of natural vegetation cover, sudden and unpredictable rainy storm that runoff water to another locations where can be finally stored. All mentioned factors have contributed in desertification of large parts of the region and the surrounding area. In addition, they worsen the environment and have negatively affected the fauna and flora in all forms of life that is clearly demonstrated through dominating and invading plant species cover the entire soil at which many are poisonous, unpalatable or ephemerals suddenly emerge and rapidly disappear with raise in temperature. The ecology of Al-Muwaqar area is a typical example of eroded and deteriorated environment. The soil is crusty, poor and lacks many of its physical and structural properties. The removal of plant cover resulted partially from human activities through unmanaged agricultural operations; heavy grazing that uprooting of high grown plant species leaving the area with less useful, poisonous and spiny drought tolerant species, well adapted to disturbed habitat. In the less disturbed sites however, some herbaceous perennials exist and partially re-vegetating the soil (Al-Matari, 1996).

In recent years, the government has approved the expansion of water harvesting technique to partially or totally resolve the hydrological challenges in the agricultural sector (Ministry of Water and Irrigation, 2016; Sixta *et al*., 2018), but optimizing water use must be based on selecting plants with a lower demand for water (Ferrández *et al*., 2003).

However, in the last decade, many of the cultivated crop species have been tried and examined for survival, adaptability and productivity in the area, under irrigation, water harvesting (either natural, or involving earth-moving), or purely rainfed conditions (Taimeh & Hattar, 2001). These included certain field crops (particularly for animal fodder), vegetables, fruit and rangeland species, but so far, none of the medicinal plants were included. This is somewhat surprising as several plant species endemic to the area are medicinal or strongly aromatic and have culinary, pharmaceutical or medicinal applications, and have close relatives from different medicinal or other economic species. Medicinal and aromatic plants comprise a large number of diverse species differ in growth habit and habitat, ecological requirements for growth, survival and productivity, and differ in chemical constituents of leaves and seeds that enable them to survive and tolerate unfavourable environmental conditions (Qasem, 1999). Certain species are known as of low water and nutrients requirements, and tolerate drought and hot weather. Others are more sensitive to disturbances and have been selected and bred as cultivated cash crops of high economic value (Qasem, 2015). Many of these species contain active chemicals in their tissues which are important to cure from human and animal diseases. They are potentially attractive for development and use in pharmaceutical and in food industries, and thus represent important natural sources of drugs, food or food additives (Yaseen *et al*., 2019; Qasem, 2020). In addition several species have high value as feed or fodder crops, particularly in the critical autumn and winter periods, and thus are of considerable ecological importance in the local rangelands (Qasem, 1997). However, species may be bred to drought and salinity tolerance/resistance and differences between species were reflected on their distribution and ecology at which certain groups are known as desert or drought tolerant

(Evans & Sadler, 2008; Golldack *et al*., 2014; Fita *et al*., 2015), others can withstand different soil conditions and characters ranging between high alkalinity and extreme acidity and/or salinity.

Reviewing the natural flora of Al-Muwaqar area (Abu-Irmaileh, 1987; 1994; Taifour & El-Oqlah, 2014), it becomes clear that some of the reported species are medicinally important including *Artemisia herba alba* Asso, *Achillea fragrantissima* (Forssk) Sch., *Anabasis syriaca* Iljin; *Crocus* spp., *Paronychia argenata* Lam., *Polygonum equisetiforme* Sibth. Et Sm., and many others. Thus it was thought that medicinal species of similar botanical and or ecological origin may be worthwhile testing and may be later considering for commercial cultivation in the area. However, the selection of the species was also based on our own experience, and observations of these in their natural habitats in the country and therefore were chosen to simulate as much as possible the wild species grown in the area, with respect to possessing almost similar morphological, physiological, anatomical and evolutionary origins; possession of low requirements of water and for nutrients; tolerance to physical disturbance, dust, pollution and soil degradation; presence in different geographical regions in Jordan, reflecting ecological tolerance; ability to reproduce vegetatively (perennials) or complete their life cycle and set seeds under stress conditions (annuals).

The objectives of this study were to investigate possible establishment, survival and productivity of three selected perennial medicinal species in Al-Muwaqar area under different water harvesting and soil conditioner treatments; evaluate other annual and perennial medicinal plant species in their ability to germinate, survive, grow and yield under Al-Muwaqar conditions; study the effect of different irrigation treatments on the productivity of the species tested and their ability to reproduce or re-vegetate in the following seasons, study the productivity of certain promising medicinal herbs grown in two contrasting ecological regions; Al-Muwaqar (Arid) and Al-Jubeiha (Mediterranean) of a relatively high rainfall for comparison as a control site, and investigate differences in the responses of the selected species to different irrigation treatments in both locations, and to compare their productivity when grown under rainfed conditions at both sites.

Materials and Methods

Six field experiments were conducted for four subsequent years. Five of these were carried out at Al-Muwaqar during the period from 1995 to 1998 while only one experiment was conducted at AI-Jubeiha, University Campus for comparison and regarded as a control. Al-Muwaqar experimental station is located 35 km southeast of Amman at 36°5' E Longitude and 31°53'N Latitude and altitude of 760 m a.s.l. (Fig. 1). Its climate is classified as an arid or transitional from Mediterranean to mild arid. Average annual precipitation is 150mm. Mean maximum and minimum air temperature in January is 13°C and 3°C, respectively and 33°C and 17°C in August. The soil is silty-clay loam, highly calcareous of low organic matter content and carbonates content varies from 20 to 70%. The slope of the experimental site is 1% and soil depth varies from 100 to 130 cm. the sub-soil has a very compacted partially cemented layer which is rich in carbonates with gravels (Taimeh & Hattar, 2001). Surface crust is usually formed after rain or irrigation and results in a very low infiltration rates. On the other hand, Al-Jubeiha Research Station, University of Jordan Campus, is located at 35 87° E Longitude and 32 02° N Latitude and an elevation of 980m a.s.l. The climate is Mediterranean with an average annual precipitation about 450 mm. The soil is clay loam contain 62.3% clay, 36.7% silt, 1.1% sand, 0.71% organic matter and a pH of approximately 7.6.

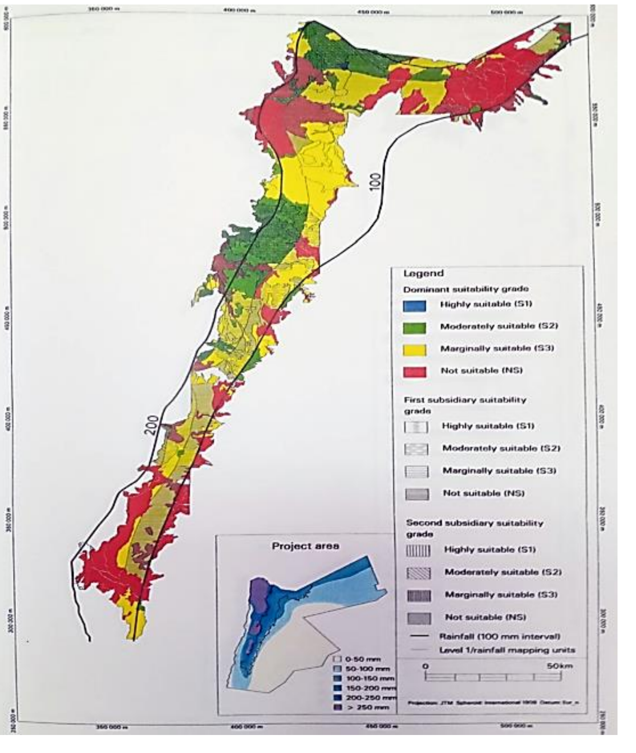


Fig. 1. Map of the study area at Al-Muwaqar site.

In the experiments, a total of 18 annual and perennial medicinal species belonging to five plant families were evaluated for germination, growth, survival, adaptability and then possible commercial cultivation in Al-Muwaqar area. These were: Anis (*Pimpinella anisum* L.), balm (*Melissa officinalis* L.), caraway (*Carum carvi* L.), chamomile (*Matricaria chamomilla* L.), fennel (*Foeniculum vulgare* Mill), mint (*Mentha viridis* L.), parsley (*Petroselinum crispum* Mill.), rosemary (*Rosmarinus officinalis* L.), sage (*Salvia officinalis* L.), safflower (*Carthamus tinctorius* L.), Roman thyme (*Thymus vulgaris* L.), Syrian marjoram (*Origanum syriacum* L.), Syrian thyme (*Thymus syriacus* Boiss), lavender (*Lavandula officinalis* L.), artichoke (*Cynara scolymus* L.), fenugreek (*Trigonella foenum-graecum* L.), yarrow (*Achillea* sp.) and garden cress (*Lepidium sativum* L.).

The following experiments were carried out:

Experiment 1. Effect of water harvesting and soil conditioner (polymer) on growth and yield of *Origanum syriacum, Salvia officinalis* and *Rosmarinus officinalis* grown under rainfed conditions in Al-Muwaqar area: Seedlings of *O. syriacum*, *R. officinalis* and *S. officinalis* were bought commercially and transplanted into the experimental site on 4th September, 1995 at a density of 12 plants/m^2. Regular watering by hosepipe was maintained until significant rainfall was received on 5th January of the 1996, after which plants grew under rainfed conditions, or different water harvesting and polymer (soil conditioning) treatments. Plants were then left to grow under 89 mm of rainfall (only 60% of MAR) until the first harvest on 20thApril, 1996. The plants were fertilized only once after first harvested using NPK (20-20-20) and 1.5% trace elements at a rate of 30 g/m^2 for benefit under subsequent harvests.

Both Experiment. 1 and Experiment 2 involved the same land preparation, on plots 1m wide and 10m long. For the water harvesting treatments the percentage of cropped to total area was 10, 20, 30 or 100%, representing cultivated areas within the plots of 1, 2, 3 and 10 m^2, respectively. Water harvesting units each was surrounded by ridges of 25 cm high and 30 cm wide. Each experiment consisting of 4 water harvesting treatments, 2 polymer levels, 3 plant species, and 4 replicates. The cultivated area was hand-dug. The polymer treatments involved incorporation of 'Alcosorb 400' polymer within the top 25cm of the soil profile for the cultivated areas, at a rate of 300g/ m^2. At harvest, data on plant height, total shoot fresh weight, leaves fresh weight; branches fresh weight, leaf number, leaf area and total dry weight of shoots were recorded.

Experiment 2. Effect of water harvesting and soil conditioner on growth and yield of *O. syriacum, S. officinalis* and *R. officinalis* grown under supplementary irrigation in Al-Muwaqar area: In this trial, seedlings of *O. syriacum*, *R. officinalis* and *S. officinalis* were transplanted in the field on 21st February 1996 at a density of 12 plants/m^2 and under different water harvesting and polymer (soil conditioner) treatments. Plants were immediately irrigated through a sprinkler irrigation system, and then grown under supplementary irrigation from 7th April, 1996 until the end of the season. Irrigation was carried out to simulate the annual rainfall average of 150 mm. Plants were fertilized as in Experiment 1, then harvested on 14th May, 1996.

In both experiments, plants were allowed to grow for a complete second growing season (1996-1997), but without any additional irrigation given. Rainfall in this latter season was 140mm, which is close to the MAR figure for the station of 150mm. Data on number of emerged or revegetated plants were taken for all species on 27thFebruary, 1997 and considered as an indicator on the species potential for adaptability and survival in Al-Muwaqar area. Plants were photographed in both experiments and notes on their growth and general performance were also taken at the end of the growing season on 15th May, 1997.

The amount of water stored in the soil was determined gravimetrically by simulating different rain storms that occurred during the experimental season. This was achieved by using sprinklers (the same as used for supplementary irrigation) to apply either 5, 7, 6, 12 or 11 mm. Five mm irrigation was used to simulate storms between 5 and 8 mm, while 5+7 mm were used to simulate the 12 mm rainfall, 5+7+6 mm irrigation were used to simulate 18mm and supplementary irrigation and 5+7+6+12 mm irrigations were used to simulate 30 mm rainfall. Storms of less than 5 mm were not simulated. Each irrigation was applied separately one hour apart. Soil samples were taken at 15 cm depth using an auger. From each cropped area, three samples were taken at the middle axis of the cropped area. Soil moisture content was determined at 0.3 and 15 bars tension using disturbed soil samples, either mixed with polymer at the same rate of field experiment, or left without polymer, using ceramic plate extractor. Bulk density values were calculated for soil treatments with and without polymer (1.1 and 1.4g/cm^3, respectively).

Experiment 3. Germination, survival and growth of 15 medicinal species grown under supplementary irrigation in Al-Muwaqar area for two years (1996 and 1997): Fifteen medicinal species were tested for adaptability, growth and survival in Al-Muwaqar area (Table 4).

Seeds of annual species or seedlings of the perennials were planted on 12th March, 1996. For perennials, 35 seedlings were transplanted into four rows per plot of 2x3 m^2 area; for annuals, seeds were hand sown over the entire plot area at similar rates usually used by local farmers, and thoroughly incorporated in the topsoil layer. Four replicate plots were used for each species.

Plants were irrigated twice a week using a sprinkler irrigation system during the period from 8th May, 1996 until 17th June, 1996. The number of emerged seedlings per plot was counted for each species on 20th May, and data on the number of plants that had survived or percentage vegetation coverage of the plot area were also taken on 3rd June and 6th August, 1996. In this experiment annuals were allowed to grow until seeding without any disturbance. Information on the ability of each species to repeat life cycle in this environment was recorded for the second growing season in 1997.

Experiment 4. Germination, survival and growth of 15 medicinal species grown under irrigation in Al-Muwaqar area for two years: This experiment was carried out in a similar way to that of experiment 3, with both being planted at the same date. However, in experiment 3, plants were supplementary irrigated after emergence once every three-weeks. Similar data on germination and survival of seedlings were taken at the same dates as those in experiment 3.

Plants in both experiments were left to grow under rainfed conditions for the 1996/1997 growing season without any further irrigation. Data on number of emerged or revegetated plants were taken on species on 27th February, 1997 and considered as an indicator on the species adaptability and survival in the area. Plants were photographed in both experiments and notes on their growth and general performance were also taken at the end of the seconed growing season on 15th May, 1997.

Experiments 5 & 6. Germination, growth and yield of six selected medicinal species grown under different irrigation treatments at AI-Jubeiha and Muwaqar: Two experiments were conducted during 1997-98 growing season and started at the same time at Al-Muwaqar and at AI-Jubeiha Research Station (University Campus). Both experiments were carried out to compare a selected number of the most promising medicinal species for their germination, growth, performance and productivity in the two locations. Six of the already evaluated species in the previous experiments were chosen, these were *M. chamomilla, F. vulgare, P. crispum, C. tinctorius, C. scolymus* and *L. sativum.*

All species were grown from seeds sown in plots each of 2 m^2. Plants of all species were grown under 3 treatments of irrigation; full irrigation, supplementary irrigation, or rainfed. The layout of experiments, date and rate of planting and other agricultural operations were the same in both locations and carried out at the same dates. However, plants in Al-Muwaqar area were almost naturally weed-free. By contrast, those at Al-Jubeiha (University Campus) were heavily weed-infested, and weeding operations faced some difficulties due to weather and mud soil before being done. Plants however, in both sites were relatively weed- free for most of the growing season.

In both experiments, the dates of emergence, and the amount and date of water added, or rainfall received, covering the whole growing season, were recorded. Number of emerged seedlings or percentage land cover of the species were measured or estimated; plant height of certain species was also recorded, and plants in-both locations were photographed in the middle and end of the growing season. At harvest, data on different growth parameters were obtained, including plant height, fresh and dry weights (after oven drying at 80°C for 48 hours); seed yield (where applicable) and number of tillers per plant (where relevant).

Statistics

In the first and second experiments, the experimental design was a split plot within a complete randomized block design with water harvesting was the main plot and polymer treatment the sub-plot. At harvest, data on plant height, total shoot fresh weight, leaves fresh weight; branches fresh weight, leaf number, leaf area and total dry weight of shoots were recorded. Each plant species was considered as a split plot experiment and analyzed separately. Plot area was 30m^2. Treatments in other experiments were laid out in a complete randomized block design. Treatments in all experiments were replicated four times and average means of all replicates in all treatments and for all measured parameters were tabulated. Data in all experiments were statistically analyzed and treatments means were compared using LSD at 5%.

Results

Experiment 1: Results of this experiment are summarised in (Table 1.) Water harvesting did not significantly affect measurements per plant of total fresh weight or leaf fresh weight of the three species, although the highest values for both growth parameters were obtained when 20% of the plot area was planted. Polymer significantly increased both growth parameters in the three species. Combination of polymer and water harvesting significantly increased the soil moisture content and gave higher growth in the three species compared with the control. On a per plot basis highest yields were obtained when 30% of the plot area was cultivated, although these were only slightly ahead of the 20% treatment. *Salvia officinalis* gave much higher yields than the other two plant species.

Experiment 2: Water harvesting significantly (p<0.05) increased leaf and total fresh weight of *O. syriacum* and *R. officinalis*. Results showed that the larger the area left for water harvesting, the better the growth of both species. However, differences were only significant between the largest (10% cropped) and the lowest water harvesting area (100% cropped) left to irrigate *R. officinalis* plants. Only the combination of water harvesting and polymer treatments significantly increased *S. officinalis* growth while polymer treatment significantly increased growth of *O. syriacum* and *R. officinalis* plants. In general, polymer significantly increased soil moisture content and this was more pronounced with the largest water harvesting area (10% cropped). Both higher infiltration rates and greater available water holding capacities may be operative here. The number of emerged and revegetated *R. officinalis*, *O. syriacum* and *S. officinalis* plants grown with or without supplementary irrigation and soil conditioner in the first year (1996) and left without irrigation in the 1997 growing season is shown in (Table 2).

In general, higher number of plants from the three species were found in plots under supplementary irrigation than in rainfed plots. Higher number of *O. syriacum* plants were present in plots receiving more harvested water (i.e. the 10% cropped plots) than other water harvesting treatments. This however, was not the case for the other two medicinal species, since higher number of *R. officinalis* and *S. officinalis* plants was found when 20-30% of the plot area was planted. The lowest number of surviving plants was found when the whole plot area was planted (Table 2).

The three species left without irrigation for two subsequent years, differences in the effect of water harvesting treatments within the species were marginal. However, *R. officinalis* appeared the best adapted while planting 100% of the plot area gave the worst stands. Addition of polymer to the soil appeared beneficial to *O. syriacum*, improving survival of this species more than the other two species tested. Higher number of *O. syriacum* plants was found with polymer than with no polymer added and in all water harvesting treatments. In contrast, higher numbers of *R. officinalis* plants were generally found in plots without any polymer added and this applied also to *S. officinalis*. However, the effect of polymer was clearly demonstrated in plots where no water harvesting was performed. *Salvia officinalis* plants were moderately affected by polymer treatment (Table 2).

As with supplementary irrigated plots in the first year, polymer treatment was necessary for survival and growth of *O. syriacum* plants grown only under rainfed conditions, but polymer seems not of similar importance or even not necessary for *R. officinalis* and *S. officinalis* plants under the same conditions, since higher number of plants from both species was found in plots where polymer was not added.

Table 1. Effect of water harvesting and soil conditioner (polymer) on total shoot fresh weight (TFW), leaf fresh weight (LFW) and total plot dry weights of *Origanum syriacum*, *Rosmarinus officinalis* and *Salvia officinalis.*

Percentage of cropped area	*O. syriacum*			*R. officinalis*			*S. officinalis*			Polymer (% soil moisture)	
	Fr Wt (g/plant)		Dry Wt (g/plot)	Fr Wt (g/plant)		Dry Wt (g/plot)	Fr Wt (g/plant)		Dry Wt (g/plot)	With	Without
	TFW	LFW		TFW	LFW		TFW	LFW			
10%	3.7	2.9	155	39.4	33.7	163	15.5	11.7	336	24.7	17.1
20%	6.0	4.5	275	40.5	34.3	307	19.0	14.3	672	25.5	17.3
30%	2.5	2.0	305	30.3	25.4	424	16.4	11.9	793	20.4	14.9
100%	3.3	2.6	-	30.5	25.8	-	13.9	10.1	-	19.3	12.9
LSD (P=0.05)	4.9	3.7	-	3.5	9.8	-	6.1	3.7	-	1.8	1.8
	Effect of polymer treatment on plant fresh weights (g/plant) or plot dry weights (g/plot)										
With	5.3	4.1	282	38.8	32.9	353	22.0	16.4	725	-	-
Without	2.5	1.9	207	31.5	26.7	343	10.4	7.6	475	-	-
LSD (P=0.05)	1.3	1.0	-	6.4	5.4	-	6.0	4.7	-	-	-

Table 2. Effect of water harvesting and soil conditioner (polymer) on total shoot fresh weight (TFW) and leaf fresh weight (LFW) of *O. syriacum*, *S. officinalis* and *R. officinalis* under supplementary irrigation simulating mean annual rainfall.

Percentage of cropped area	*O. syriacum*		*S. officinalis* fresh weight (g/plant)				*R. officinalis*		Polymer treatment (% Soil moisture)	
	Fresh Wt (g/plant)		With polymer		Without polymer		Fresh Wt (g/plant)			
	TFW	LFW	TFW	LFW	TFW	LFW	TFW	LFW	With	Without
10%	35.8	23.2	95.8	65.9	60.9	42.5	33.6	24.9	24.4	18.4
20%	28.8	19.1	98.6	66.4	51.5	30.6	30.5	22.7	23.2	16.8
30%	20.3	12.8	68.6	40.3	43.0	25.7	29.8	22.2	21.3	16.3
100%	17.5	11.4	40.8	26.3	34.8	20.7	23.5	16.2	17.9	13.8
LSD (P=0.05)	6.9	3.8	33.3	21.4	33.3	21.4	9.5	7.1	2.2	2.2
	Effect of polymer treatment on *S. syriacum* and *R. officinalis* plant fresh weights (g/plant) under supplementary irrigation and 100% cropped area									
With polymer	31.0	20.9	-	-	-	-	36.5	27.2	-	-
Without polymer	20.1	12.4	-	-	-	-	22.2	15.8	-	-
LSD (p=0.05)	2.8	1.6	-	-	-	-	4.7	4.0	-	-

Table 3. The Effect of Water harvesting and polymer treatments on survival number of *O. syriacum*, *S. officinalis* and *R. officinalis* plants per plot area.

Percentage ofcropped area	*O. syriacum*		*S. officinalis*		*R. officinale*		*O. syriacum*		*S. officinalis*		*R. officinale*	
	Without supplementaryirrigation in first Year						With supplementaryirrigationin first Year					
	With polymer (+) or without polymer (-)											
	+	-	+	-	+	-	+	-	+	-	+	-
10%	3	1	2	5	6	6	9	7	10	9	8	8
20%	3	2	4	3	6	4	3	4	13	17	6	10
30%	2	2	3	2	3	8	5	4	13	23	11	16
100%	1	0	1	3	1	7	3	1	4	9	1	8

Experiment 3: Emergence of all species planted from seeds was fulfilled within a short period from sowing, except *M. officinalis* which failed completely to germinate (Table 3).

Other perennials planted from seeds were healthy and survived the early period of this experiment. *C. tinctorius* and *C. scolymus* showed a high number of emerged seedlings, although three months after emergence there was a clear reduction in the number of surviving seedlings. At about 3 months from emergence, a high number of *M. viridis*, *F. vulgare*, *P. crispum*, *Thymus* spp., *Achillea* sp., *L. officinalis* and *C. scolymus* plants were still alive and passed the long-hot dry conditions period in the summer. Apart from *C. carvi* and *M. officinalis*, all the annual species successfully completed their life cycle and. produced seeds (Table 3).

Experiment 4: The number of emerged seedlings was not greatly different for all tested species from that in experiment 3 (Table 4). However, some reduction in the numbers of surviving plants of the perennial species was found compared with their numbers under irrigation (experiment 3). At 3 months after emergence, further reduction in the numbers of remaining plants was observed, although a relatively good number of *M. viridis*, *Achillea* sp., *P. crispum* and *L. officinalis* survived the hot summer period. *Carthamus tinctorius*, *F. vulgare*, *L. sativum*, *M. chamomilla*, *T. foenum-graecum* and *P. anisum* were all successfully completed their life cycle and produced seeds in full- rather than supplementary-irrigated plots. Plants under full irrigation appeared more vigorous and covered a higher proportion of the plot area than the supplementary-irrigated plants.

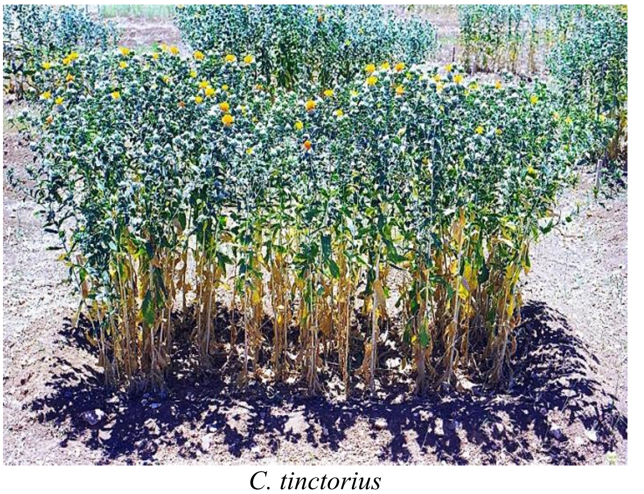
Differences in number of plants in full-irrigation plots between the first and second year were not high for certain species including *L. sativum*, *L. officinalis*, *P. crispum*, *Achillea* sp. and *C. scolymus*. However, plants grown with supplementary irrigation were reduced in number in the second year since left to grow naturally and almost without irrigation. *Mentha viridis*, *T. syriacus* and *T. vulgaris*, *T. foenum-graecum* and *P. anisum* were severely affected and most of these plants died out. However, *P. anisum*, *Achillea* sp. and *C. scolymus* were the least affected. Nevertheless, many of the surviving species were able to maintain themselves, flowered and reached the marure stage.

Number of all species as well as their growth was reduced in the third growing season compared with the second season and under both sublimentary and full irrigation treatments. However, higher number of plants was recorded under full irrigation compared with those in supplementary irrigated plots and for all species. Fully irrigated plants of all species were more vigorous and better covering the plot area than those grown under supplementary irrigation (Table 4).

Experiments 5 & 6: Much difference was not observed in the germination dates of the different species between the two locations, although a delay in germination for few days was found at Al-Muwaqar site (Table 5).

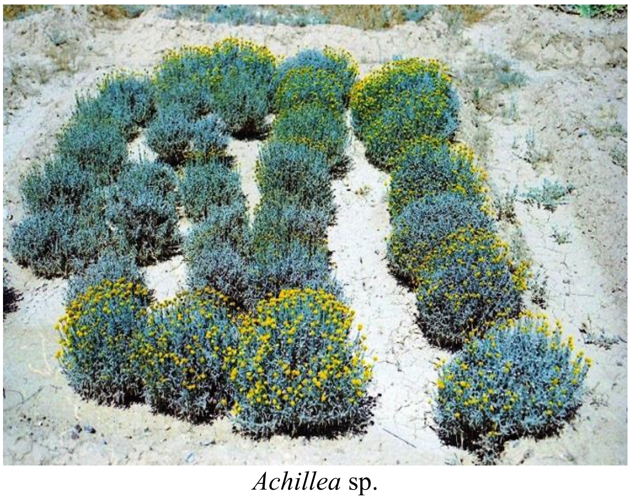
Results showed that in general the percentage of land cover, plant height, number of heads (for *C. tinctorius*), shoot dry weight and seed weight (for *C. tinctorius* and *L. sativum*) were higher at Al-Jubeiha than at Al-Muwaqar. This applied to both irrigation treatments, there was no irrigation (control) and for almost all species. However, differences in the growth of *F. vulgare* and *C. scolymus* were very small between the two locations, and actually growth of *C. scolymus* in terms of shoot dry weight was better at Al-Muwaqar than at Al-Jubeiha under both full and no irrigation treatments. The effect of irrigation on all species in both locations was clear. Ground cover and growth percentage was better with irrigation (Table 5). This applied for both locations, but differences were found between species in their responses to irrigation treatments. Considering percentage of ground cover, it appeared that *C. tinctorius*, *M. chamomilla* and *C. scolymus* were the least responsive species to irrigation. In term of shoot dry weight, *C. scolymus* and *M. chamomilla* were the least responsive species to irrigation at Al-Muwaqar.

Over all experiments conducted throughout four consequetive years at Al-Muwagar site, visual estimation on growth and survival of the species tested showed that eight species may be regarded as suitable to grow at this area (Table 6). *Achillea* sp. was the most important followed by *C. tinctorius* and *C. scolymus* (Fig. 2) that showed the highest score. Other five species were more or less similar in growth and performance under these conditions.



C. tinctorius

C. scolymus



Achillea sp.

Fig. 2. The most adapted medicinal species to arid conditions at Al-Muwaqar site, showing species at flowering stage.

Table 4. Germination and survival rates (no. of plants per plot) of 15 selected medicinal species over three growing seasons (experiments 3 and 4).

Plant species	Full irrigation				Supplementary irrigation				
	Emergence	Emergence + 2wks	Emergence + 3mo.	May 3rd year	Emergence	Emergenc e+ 2wks	Emergence + 3mo.	May3rd year	Status
Achillea sp.	-	-	35	34	-	-	25	22	Flowering
C. carvi	-	-	-	-	-	-	-	-	-
C. scolymus	114	111	33	35	105	81	4	18	Seeding
C. tinctorius	504	567	540	0	470	305	300	20	Seeding
F. vulgare	-	-	52%	20%	-	-	22%	10%	Seeding
L. officinalis	34	34	28	17	34	28	13	8	Vegetative
L. sativum	-	-	75%	40%	-	-	52%	31%	Seeding
M. chamomilla	-	-	19%	6%	-	-	7%	3%	Seeding
M. officinalis	-	-	-	-	-	-	-	-	-
M. viridis	35	35	21	2	32	31	14	4	Vegetative
P. anisum	-	-	28%	4%	-	-	5%	0	Seeding
P. crispum	-	-	24%	30%	-	-	13%	18%	Seeding
T. foenum-graecum	-	-	20%	0	-	-	18%	0	-
T. syriacus	-	-	30%	0	-	-	13%	0	-
T. vulgaris	14	17	13	0	14	12	2	0	-

Discussion

Results of the first and second experiments clearly showed the importance of soil conditioner and water harvesting in maintaining, survival, growth and productivity of *O. syriacum*, *S. officinalis* and *R. officinalis* plants grown under arid conditions in Al-Muwaqar area (Table 1) and emphasized the importance of soil conditioner in improving soil conditions and increasing the soil water holding capacity and moisture availability. Species however, were markedly different in their ability to survive and to develop under sever harsh environmental conditions prevailing at Al-Muwaqar area. Polymer appeared more beneficial to *O. syriacum* than for other two species since the number of emerged plants of this species was lower in polymer-untreated plots. In contrast, *R. officinalis* and *S. officinalis* had higher number of revegetated plants in plots which received no polymer (Table 3) but more pronounced under supplementary irrigation. These results indicate that water requirements of *O. syriacum* may be much higher than that for *R. officinalis* or *S. officinalis* since the first is a leafy species grown mainly for leaf production while *R. officinalis* is a flowering ornamental of needle like leaves with low water requirements and thrives in full sun (https://www.gachina.com/plant-of-the-weed/). Plants of this species under deficit irrigation showed a conservative strategy in the use of water, reducing stomatal conductance and therefore was suggested for the successful gardening of plants in semiarid conditions (Nicola´s, 2008). *Salvia officinalis* has moderate water requirements but cannot adapt to a wide range of availability of water while other species of this genera are considerate xerophytes (Corell *et al*., 2012). The plant is a drought and salt tolerant may be used in areas affected by these stresses (Narusaka *et al*., 2003; Jan *et al*., 2017; Aslani & Razmjoo, 2018). It has been reported that sage is very drought tolerant and does not like sitting in wet soil. The leaves get mildew if they are allowed to sit damp, or water infrequently (https://www.thespruce.com/growing-sage-1402599).

Considering the effect of water harvesting, the lowest number of emerged plants of the three species in the 3rd year was in the entirely grown (100% planted area) plots and for the three species (Table 3). This may be due to the high intraspecific competition for water and space between individuals of thick stands of the three species in treatment of zero water harvesting. However, in all treatments, *R. officinalis* was the best survived and performed better than the other two species tested.

Results of the 2nd year experiments revealed that the ability of the species greatly varied to emerge, revegetate and their seedlings to survive and to grow under Al-Muwaqar conditions (Tables 4 & 5). Germinated species were clearly different in responses to irrigation and / or soil conditioner.

Data of the screening experiment (Experiment 3) demonstrated that some species tested produced seeds, while others successfully passed the dry hot summer period. Although supplementary irrigation could have improved the soil cover by most species tested, but certain species maintained themselves and continued growing with a minimum water supply or under rainfed conditions. In general, plants grown from transplants were less affected by prevailing environmental conditions than those grown from seeds except for certain species (*C. tinctorius*, *C. scolymus* and *L. sativum*) that showed high germination and satisfactory growth under such conditions. This probably due to better seedlings tolerance of these species to drought conditions than seeds that require high soil moisture for imbibition and germination although seeds are known as better surviving drought conditions and may enter into a long dormancy period in the soil. Seeds of certain species such as *C. carvi* and *M. officinalis* failed to germinate in Al-Muwaqar area which may be due to internal and /or external factors. However, moisture availability greatly improved germination and seedlings growth and survival of all other species tested (Tables 4 & 5).

Table 5. Comparative growth parameters for the different selected medicinal species in relation to irrigation treatments at Al -Muwaqar and Al-Jubeiha sites.

Treatment/ species	Amount of water				Days taken to germinate (day)		Percentage cover (%)		Plant height (cm)		No. of heads (No.)		Shoot dry weight (g)	
	Jubeiha		Muwaqar											
	Rainfed (mm)	Irrigation (L)	Rainfed (mm)	Irrigation (L)	Jubeiha	Muwaqar	Jubeiha	Muwaqar	Jubeiha	Muwaqar	Jubeiha	Muwaqar	Jubeiha	Muwaqar
Full Irrigation														
C. scolymus	-	-	-	-	56	56	19	17	-	-	-	-	94	121
C. tinctorius	-	-	-	-	40	42	96	71	74	48	19	4	2747	802
F. vulgare	-	-	-	-	38	40	67	54	-	-	-	-	292	277
L. sativum	437	420	159	420	12	18	87	85	54	29	-	-	1386	401
M. chamomilla	-	-	-	-	68	74	72	46	-	-	-	-	349	36
P. crispum	-	-	-	-	58	74	78	37	-	-	-	-	192	109
Supp. irrigation														
C. scolymus	-	-	-	-	56	56	30	12	-	-	-	-	80	701
C. tinctorius	-	-	-	-	40	42	92	72	56	47	17	4	1417	626
F. vulgare	-	-	-	-	38	40	52	42	-	-	-	-	104	152
L. sativum	437	200	159	200	12	18	79	68	54	22	-	-	1020	117
M. chamomilla	-	-	-	-	8	74	61	49	-	-	-	-	68	25
P. crispum	-	-	-	-	0	74	69	31	-	-	-	-	216	81
No Irrigation														
C. scolymus	-	-	-	-	5 6	56	25	13	-	-	-	-	54	82
C. tinctorius	-	-	-	-	3 0	42	68	72	50	30	16	2	6	22
F. vulgare					8	40	53	51			-	-	79	62
L. sativum	437	0	159	0	1 2	18	70	60	47	18	-	-	1025	106
M. chamomilla	-	-	-	-	0	74	64	37	-	-	-	-	69	13
P. crispum	-	-	-	-	0	74	63	20	-	-	-	-	46	36

Percentage cover 0% denotes that no plants in the plot area and 100% denotes that plot area is fully vegetated by the plant

Table 6. Species appeared adapted to Al-Muwaqar conditions which could be grown as medicinal crops as judged from their growth and ability to complete their life cycles. Scores represent visual estimation of species survival and growth in all experiments.

Plant species	Life cycle	Score out of 10
Achillea sp.	Perennial	9.5
C. scolymus	Perennial	7.0
C. tinctorius	Annual	7.6
F. vulgare	Perennial	6.6
L. officinalis	Perennial	6.5
L. sativum	Annual	6.0
P. crispum	Perennial	6.9
R. officinalis	Perennial	8.2

Visual estimation at which zero score denotes that no plants growth in the plot area10 score denotes that plot area is totally covered by the plant

In the 3rd growing season, no irrigation was provided to all species in all treatments, while moisture availability appeared not crucial for the survival of certain species such as *L. sativum* and *Achillea* sp. These results might be due to that *L. sativum* plants were short-lived, finish life cycle and reached maturity early in the spring before the start of hot period usually occurring from April onward and therefore escaped drought effect. *Achillea* sp. may be well adapted to such drought conditions and the desert, although plants were slightly shorter under supplementary irrigation compared to full irrigation but differences in the survived number of plants of this species grown under supplementary irrigation in the 2nd and 3rd years were marginal. While no water was given to plants of this species during the 3rd growing season, but this did not affect its survival and growth compared with the 2nd year grown plants. Different species of *Achillea* are well known as tolerating drought conditions and widely spread in arid and semiarid regions in Jordan (Taifour & El-Oqlah, 2014; Qasem, 2020).

The low number of *C. tinctorius* plants in the 3rd year compared with the 2nd year does not reflect the ability of the species to survive in Al-Muwaqar area rather than seeds of this species were dispersed out of the experimental site in the second year growth. Seeds of this plant are hairy and able to disperse a far distance by wind currents. Safflower (*C. tinctorius*) is a considerable salt resistance (Kaya, 2011; Hussain *et al*., 2016) and a promising alternate crop in dryland agro-ecosystems (Kar *et al*., 2007). On the other hand, the number of plants of *C. scolymus* was higher in 3rd than in 2nd year although plants were not irrigated in the 3rd growing season which may well reflecting the ability of this species to survive and to potentially resume growth under such conditions.

Results of the 3rd/4th growing season revealed that growth and performance of most tested species were better at Al-Jubeiha than at Al-Muwaqar site. However, differences in germination of all species and in growth of certain species were marginal between the two locations indicating the ability to grow and reproduce in both sites regardless of prevailing drought conditions and deteriorated environment in Al-Muwaqar. It appeared that irrigation affected more at Al-Jubeiha than at Al-Muwaqar reflecting better adaptation of species under Al-Muwaqar conditions characterised by poor growth factors and the high responses of these to more supply of growth factors at Al-Jubeiha reflected on their growth and production. Percentage of land cover was almost the same for the *C. scolymus* plants grown at Al-Muwaqar location and under all irrigation treatments (Table 5). This species however, appeared well adapted to Al-Muwaqar conditions since prefers calcareous soils with high pH and can tolerate saline conditions (Benlloch-Gonzalez *et al*., 2005). Although in these experiments, *C. scolymus* was evaluated at seedling stage, but results of Experiments 4 and 5 were highly promising. Therefore it was decided to examine germination, survival, growth and productivity during the next 4th /5th growing season and comparing the species grown from seeds and transplants under irrigation and rainfed conditions but with some management's for water harvesting in all treatments and results were highly promising. Artichoke (*Cynara scolymus* L.) has been reported as a species tolerating saline conditions and its water requirements for growth and productions is not high. It is a herbaceous perennial plant belonging to the Compositae family that grows naturally in severe habitat conditions with high temperature, high salinity and drought in the summer (Benlloch-Gonzalez *et al*., 2005).

Conclusion

Results of the four years of experimentation on medicinal species indicate that there is a good potential for medicinal plants to be grown in Al-Muwaqar (arid) area. Although the productivity of most species was significantly lower than that in other locations in Jordan (e.g. Al-Jubeiha, where comparative trials were carried out), but might be of a higher quality in terms of chemical constituents concentrations. Experience with a soil conditioner and water harvesting showed that soil moisture contents were increased and this greatly improved the growth of *R. officinalis*, *S. officinalis* and *O. syriacum*. The effect of soil conditioner lasted for a minimum of two years after application and was most beneficial to *O. syriacum* plants. However, *R. officinalis* was the best of the first three species tried in terms of response to the combination of both the soil conditioner and water harvesting and was clearly well-adapted to Al-Muwaqar conditions. Differences were obtained between medicinal species in their responses to irrigation treatments, and thus ability to genninate, survive and develop in Al-Muwaqar area. Although supplementary irrigation improved soil cover by most species tested, certain medicinal species were able to survive and to grow with a minimum supply or flush of water. Many of the species tested successfully completed life cycles and set seeds (*L. sativum*, *F. vulgare*, *C. tinctorius*, *C. scolymus*), while others (*M. viridis*, *P. crispum*, *Thymus* spp., *O. syriacum*) appeared to require large quantity of water or high soil moisture availability for growth and yield. Certain species (e.g. *L. sativum* and *M. chamomilla*) were able to complete their life cycle during winter or early spring season and thus escaped the drought and high temperatures of the summer. *Foeniculum vulgare*, *C. tinctorius*, *C. scolymus*, *L. sativum* and *M. chamomilla* showed continued good growth during the 4-year experiments. *Cynara scolymus* perfonned the best, especially with full or supplementary irrigation. *Carthamus tinctorius* L. is a considerable salt resistance species and thus cultivated in arid and semi-arid regions where soil salinity is one of the major threats to agriculture. It is a promising alternate crop in dryland agriculture due to its growth potential under water stress without a substantial reduction of oil and seed yields. Comparing growth of the tested medicinal species during the fourth year growing season in the two locations, plants at Al-Jubeiha showed much better growth than at Al-Muwaqar. Differences were observed in germination percentage, overall growth, and response of the tested species to irrigation treatments within and between locations.

Based on the results obtained from our work in Al-Muwaqar area we recommend the following:

1. There is a need for more screening experiments to be carried out on other medicinal species in Al-Muwaqar area; 2. *Cynara scolymus*, *F. vulgare* and *C. tinctorius* were most promising and should be promoted on a semi-commercial scale under water harvesting treatments (including cultivation in contour furrows), in order to obtain and complete information on their growth and productivity in Al-Muwaqar area; 3. Despite the small amounts of water used in irrigation, and the absence of fertilization, *C. scolymus* was able to survive, yearly resume growth, and produce heads and seeds. This species appeared of greatest potential for cultivation in the Muwaqar area under water harvesting techniques. Although it responded well to soil conditioner, the same effect could probably be achieved more economically with the use of animal manure.

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References

Abu-Irmaileh, B.E. 1987. Al-Mowaggar: The challenge" plant cover" distribution and habitats. *Dirasat.*, 14(11): 141-149.

Abu-Irmaileh, B.E. 1994. A1-Mowaqqar, a model for arid rangelands in Jordan: botanical composition and productivity. *J. Arid Environ.*, 28(2): 155-162.

Al-Matari, A.K. 1996. *Establishment and Growth of Three Medicinal Plant Species at Al-Muwaqar*. MSc. Thesis. Faculty of Graduate Studies, University of Jordan, Amman, Jordan. 64 pp.

Aslani, H. and J. Razmjoo. 2018. Common sage (*Salvia officinalis* L.) responses to salinity and drought stresses in Isfahan region. *Acta Hort.*, 1190: 145-150.

Benlloch-Gonzalez, M., J.M. Fournier, J. Ramos and M. Benlloch. 2005. Strategies underlying salt tolerance in halophytes are present in *Cynara cardunculus*. *Plant Sci*., 168: 653-659.

Corell, M., M.C. Garcia, J.I. Contreras, M.L. Segura and P. Cermeño. 2012. Effect of water stress on *Salvia officinalis* L. bioproductivity and its bioelement concentrations. *Commun. Soil Sci. Plant Anal.*, 43: 419-425.

Evans, R.G. and E.J. Sadler. 2008. Methods and technologies to improve efficiency of water use.*Water Resour. Res.*, 44: 15.

Ferrández, T., S. Rubio, A. Torrecillas, J.J. Alarcón and M.J. Sánchez Blanco. 2003. Crecimiento, floración y relaciones hídricas de plantas de romero bajo distintas condiciones de riego. *I. Jornadas Ibéricas de Plantas Ornamentales,* Sevilla, 1: 51-60.

Fita, A., A. Rodríguez-Burruezo, M. Boscaiu, J. Prohens and O. Vicente. 2015. Breeding and domesticating crops adapted to drought and salinity: a new paradigm for increasing food production. *Front Plant Sci*., 6: 978.

Golldack, D., C. Li, H. Mohan and N. Probst. 2014. Tolerance to drought and salt stress in plants: Unraveling the signaling networks. *Front Plant Sci.,* 5: 151. https://doi.org/10.3389/fpls.2014.00151.

https://www.gachina.com/plant-of-the-weed/

https://www.thespruce.com/growing-sage-1402599.

Hussain, M.I., D.A. Lyra, M. Farooq, N. Nikoloudakis and N. Khalid. 2016. Salt and drought stresses in safflower: A review. *Agron Sustain Dev.,* 36 (1): 1-31. https://doi.org/10.1007/s13593-015-0344-8

Jan, S.A., N. Bibi, Z.K. Shinwari, M.A. Rabbani, S. Ullah, A. Qadir and N. Khan. 2017. Impact of salt, drought, heat and frost stresses on morpho-biochemical and physiological properties of *Brassica* species: An updated review. *J. Rural Dev. Agri.,* 2(1): 1-10.

Kar, G., A. Kumar and M. Martha. 2007. Water use efficiency and crop coefficients of dry season oilseed crops. *Agric. Water Manag.,* 87(1): 73-82.

Kaya, D.M., S. Bayramin, G. Kaya and O. Uzun. 2011. Seed vigor and ion toxicity in safflower (*Carthamus tinctorius* L.) seedlings produced by various seed sizes under NaCl stress. *Arch. Biol. Sci.,* 63(3): 723-729.

Ministry of Water and Irrigation. 2016. National Water Strategy 2016 - 2025. Hashemite Kingdom of Jordan.

Narusaka, Y., K. Nakashima; Z.K. Shinwari, Y. Sakuma, T. Furihata, H. Abe, M. Narusaka, K. Shinozaki and K.Y. Shinozaki. 2003. Interaction between two cis-acting elements, ABRE and DRE, in ABA-dependent expression of Arabidopsis rd29A gene in response to dehydration and high salinity stresses. *The Plant J.,* 34(2): 137-149.

Nicola´s, E. 2008. Annual water status, development, and flowering patterns for *Rosmarinus officinalis* plants under different irrigation conditions. *Hort. Sci*., 43(5): 1580-1585.

Qasem, J.R. 1997. *Medicinal and Aromatic Plants*. (Theoretical). 1997. Al- Quds Open University Publications, Amman, Jordan. 450 pp. ISBN 978-9957-467-64-7.

Qasem, J.R. 1999. Assessment of the natural vegetation in the Jordan Valley. 1999. Jordan Valley Authority and The German Technical Cooperation (GTZ). Ministry of Water and Irrigation, Amman, Jordan. 182 pp.

Qasem, J.R. 2015. Prospects of wildmedicinal and industrial plants of saline habitats in the Jordan Valley. *Pak. J. Bot.,* 47(2): 551-570.

Qasem, J.R. 2020. *The Coloured Atlas of Medicinal and Aromatic Plants of Jordan and Their Uses*. Volumes 1, 2 & 3. Cambridge Scholars Publishing. Newcatle, Upon Tyne, UK. 1399 PP.

Sixta, G.N., L. Klerkxb and T.S. Griffina. 2018. Transitions in water harvesting practices in Jordan's rainfed agricultural systems: Systemic problems and blocking mechanisms in an emerging technological innovation system**.** *Environ. Sci. Policy.,* 84: 235-249.

Taifour, H. and A. El-Oqlah. 2014. Jordan Plant Red List. Royal Botanic Garden. Volume 1, 1256 pp.

Taimeh, A.Y. and B.L. Hattar. (Eds.). 2001. Improvement of agricultural productivity in arid and semi-arid zones of Jordan. Project no: SEM/03/628/021. Final Report, Volume 2, 232pp.

Yaseen, G., M. Ahmad, S. Shinwari, D. Potter, M. Zafar, G. Zhang, Z.K. Shinwari and S. Sultana. 2019. Medicinal plant diversity used for livelihood of public health in deserts and arid regions of Sindh-Pakistan. *Pak. J. Bot.,* 51(2): 657-679.

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