The Journal of Agricultural Sciences - Sri Lanka
Vol. 21 No 2, May 2026. pp 514-533
https://doi.org/10.4038/jas.v21i2.11316

REVIEW

Role of Farmer Field Schools in Challenging Weed Management Under Climate Change in Jordan as an Example for Developing Countries

M Ateyyat[1*], B Abu-Irmaileh[2], S Araj[2], N Salem[2], and L Al- Banna[2]

Received: 13th November 2024 / Accepted: 14th November 2025

ABSTRACT

Purpose: *This review aims to focus on the role of field farmer schools in solving the problems related to weed management under climate change in developing countries, taking Jordan as an example. Therefore, awareness helps farmers adapt to emerging weed issues and incorporate effective control strategies. This is especially true in regions like Jordan, where low-input farming systems are common, and there is a need for trained extension agents to educate communities on agroecology and weed management.*

Research Method: *A structured literature search across major academic databases and synthesis process were used in this review article to ensure comprehensive coverage of the role of FFSs to deal with weed problems under climate change, where Jordan was used as a case study representative of developing countries. The search covered 104 publications up to 2025 to capture two decades of evolving knowledge on FFS and climate-related challenges in agriculture. Jordan as a case study, highlighting specific FFS experiences, challenges, and lessons applicable to broader developing-country contexts.*

Findings and Values: *FFSs provide practical, on-site training, helping farmers learn modern weed control strategies. These schools have proven successful in spreading knowledge to neighboring farms, raising collective awareness of sustainable management practices across farming communities. A collaboration between the governmental bodies and academic researchers is requested to activate the role of FFSs to produce a generation of pioneer farmers who could circulate their knowledge to other farms. However, a success in Jordan happened in Farmer Schools in enhancing the use of soil solarization to combat soil-borne diseases and weeds in the Jordan Valley.*

Keywords: *Climate change, Developing countries, Ecosystems, Farmer field schools, Weed genetic plasticity, Weed management*

INTRODUCTION

Changes in the environmental conditions in any ecosystem influence the spread, population dynamics, and life cycle duration of its living biota. Competitions among living organisms have decisive effect on their survival and distribution (Patterson 1995). Plant species respond differently to many edaphic, biotic and climatic factors.

Eco-physiological responses of plant species are decisive traits, which make them more competitive and dominant or become distinct, thus, affecting the outcome of the ecosystem's floral composition. Plant species adjust to environmental stresses via modifications in

[1]Department of Plant Production and Protection, Faculty of Agricultural Technology, Al-Balqa Applied University, Al-Salt 19117, Jordan.

[2]Department of Plant Protection, School of Agriculture, The University of Jordan, Amman, 11942, Jordan.

*ateyyat@bau.edu.jo

mechanisms occurring at the morphological, anatomical, and physiological levels (Gratani 2014). Plant adaptability in agro-ecosystems is affected by the plasticity of plant genotype (Laitinen 2024, Li *et al*. 2025). Weed populations include individuals with the ability to adapt and flourish in different types of habitats. Adaptive plastic responses in colonizing weeds help them maintain function and fitness across a range of environments and influence their ecological spread and response to natural selection (Sultan 2000, Daehler 2003, Pichancourt & van Klinken 2012). Certain weed species respond rapidly to disturbances giving them a competitive advantage over the less aggressive crop species (King *et al.* 2025).

Increasing environmental stress makes crops more vulnerable to attack by insect pests and plant pathogens and less competitive with noxious weeds (Amare 2016). Contrary to crops, weeds have greater genetic plasticity because weed genomes are not interrupted. Weed populations include individuals with the ability to survive and flourish in various habitats more rapidly than crops due to their high genetic variation and plasticity (Baker 1965).

Weed species with broad ecological attributes can adapt to new environmental conditions that differ from their endemic regions (Clements & Ditommaso 2011, Crossman *et al.* 2011, Roger *et al.* 2015). Weeds, capable of rapid dispersal and establishment, have the potential to invade new areas and expand their range. Native weed species may become less competitive and may be replaced by more aggressive invading species, resulting in floral changes. However, changes in climate may encourage the native species and/or sleeper weeds in the area to become more aggressive (Bridges 1992).

Changes in weed flora of agro-ecosystems have been recorded in Europe over the past decades (Amare 2016). Many invasive weed species have spread into new areas beyond their original habitats in China, Australia, South Africa and the United States, and have found suitable habitats influenced by climate change (Patterson 1995, Ziska & George 2004, Beaumont *et al.* 2014, Roger *et al.* 2015, Allen & Bradley 2016, Wan *et al.* 2017, Byrd *et al.* 2018). The weeds, *Amaranthus retroflexus* and *Abutilon theophrasti*, have expanded their range in northern areas of Europe, including exotic and potentially invasive species such as *Panicum dichotomiflorum* and *Datura stramonium* (Breitsameter *et al.* 2014). Increased levels of atmospheric CO_2 and temperature are among the predicted changes in global climate. Any direct or indirect consequences of raising CO_2 levels would differentially affect the growth or fitness of weeds and crops, and would alter weed–crop competitive interactions; however, the outcome depends on the individual set of conditions (Patterson 1995).

Normally, plants respond positively to increasing CO_2 levels, which stimulate photosynthesis, increase water-use efficiency (ratio of CO_2 uptake to evapotranspiration), and reduce stomatal aperture in plants, leading to increased production of vegetative and reproductive growth of existing plant communities (Rogers *et al.* 2007) if soil water is available. However, drought makes crops less competitive with weeds, as water-use efficiency of many weeds is higher than that of most crops, especially shallow-rooted crops (Patterson 1995). Thus, due to climate change, the growth or fitness of plant species would be *differentially affected* and weed–crop competitive interactions would be altered (Milchunas & Lauenroth 1995). Generally, elevated CO_2 improves C_3 plant photosynthesis, yield, and growth more than C_4 plants because it inhibits photorespiration in C_3 species (Hall & Allen 1993, Ziska 2001, Bleier & Jackson 2007, Rajkumara 2007, Shahidul Haque *et al.* 2014).

Chandrasena (2009) demonstrated that while high temperatures favor C_4 weeds, most weed species are C_3, meaning competition with C_3 crops is primarily driven by C_3 weeds. It is difficult to predict the future of weed–crop interactions, considering all possible combinations affecting crops and weeds under various changes in the global climate. Changes in agro-ecosystem composition are also influenced directly or indirectly by agronomic practices. Agro-ecosystems with high agronomic activities are expected to be colonized by newly introduced weed species (Hobbs & Huenneke 1992, Low & Booth 2007).

A key to designing an effective weed management strategy (*Integrated Weed Management, IWM*) is understanding weed–crop interaction. Early control of weeds prevents establishment, seed production, and invasion by new competitive species (McDonald *et al.* 2009). IWM strategies that respond to the existing weed composition should be constructed and communicated to farmers within their farming communities.

In view of the complicated combined future impacts of climatic changes, a basic knowledge of weed biology and ecological factors for weed existence in the place of origin is *essential* to design effective weed management strategies (Holm *et al.* 1977). Our concern in this article is to raise farmers' awareness of the anticipated changes in weed spread in their ecosystems and to reduce their impact on crop production.

Bio-geographical zones and agro-ecosystems in Jordan

Even though it is a small country of about 90,000 km^2, Jordan is characterized by a rich flora with approximately 2500 plant species. The country lies within semi-arid and arid climatological zones. Vegetative cover is divided into four different biogeographical zones (Fig. 1). Four principal bio-geographical regions are recognized in Jordan: Mediterranean, Irano-Turanian, Saharo-Arabian, and Sudanian (representing *tropical penetration*) (Long 1957, Al-Eisawi 1985, Al-Eisawi 1996). These zones extend from north to south in a narrow band and from west to east within about 250 km. They are well distinguished in some parts of the country but *intermingle* in certain areas (Fig. 1).

Borderlines between regions are only indicative, and some plant species can be found across several regions. Vegetation cover reflects many influences including geology, altitude, soil type, microclimate, and human activity (Taifour *et al.* 2022).

Specific climatic conditions of the major bio-geographical zones in Jordan

Mediterranean bioclimatic region: This region lies in the highlands with altitudes of 700 m above sea level. It receives the highest of rain, between 300 to 600 mm annually. The soil is best suited for rain-fed agriculture and horticulture.

Irano-Turanian bioclimatic region: The Irano-Turanian region surrounds the Mediterranean zone, forming a narrow strip of variable width, except in the north, where it extends eastwards along the Jordanian-Syrian border. Altitude ranges between 500-700 m above sea level. Annual average of precipitation lies between 150 to 300 mm. Mean annual maximum temperature is 15-25°C, and mean annual minimum temperature is 2 5°C. This region is at the borders for rain-fed agriculture and predominantly used for grazing (Ababsa 2013).

Saharo-Arabian bioclimatic region: The Saharo-Arabian region is the largest zone, which forms about 80 % of the total land area of the country. It covers the flat eastern area, known as Badya (semi-desert), bordering the Irano-Turanian region. Altitude ranges between 600-700 m above sea level in most parts but rises to 1,200 m at the Jordanian Syrian borders. Annual average of rain ranges between 100 to 150 mm quickly dropping to 50 mm further east and south. Mean annual maximum temperature is 15-20°C and mean annual minimum temperature is 2-15°C. This area is classified as rangeland for grazing. Some scattered cultivated fields concentrated in the watersheds of valleys (wadies), where water is available (Ababsa 2013).

Sudanian bioclimatic region: This region represents a penetration of tropical elements, starting from the Jordan rift valley in the north, and encompasses the Jordan valley surrounding the Dead Sea, Wadi Araba down south to Aqaba at the Red Sea. Altitude falls between -400 m (below sea level), the lowest place on earth with a unique environment at 1,200 m above sea level in the southern mountains. Annual average of rain ranges between 50-100 mm. Mean annual maximum temperature is 20-35°C

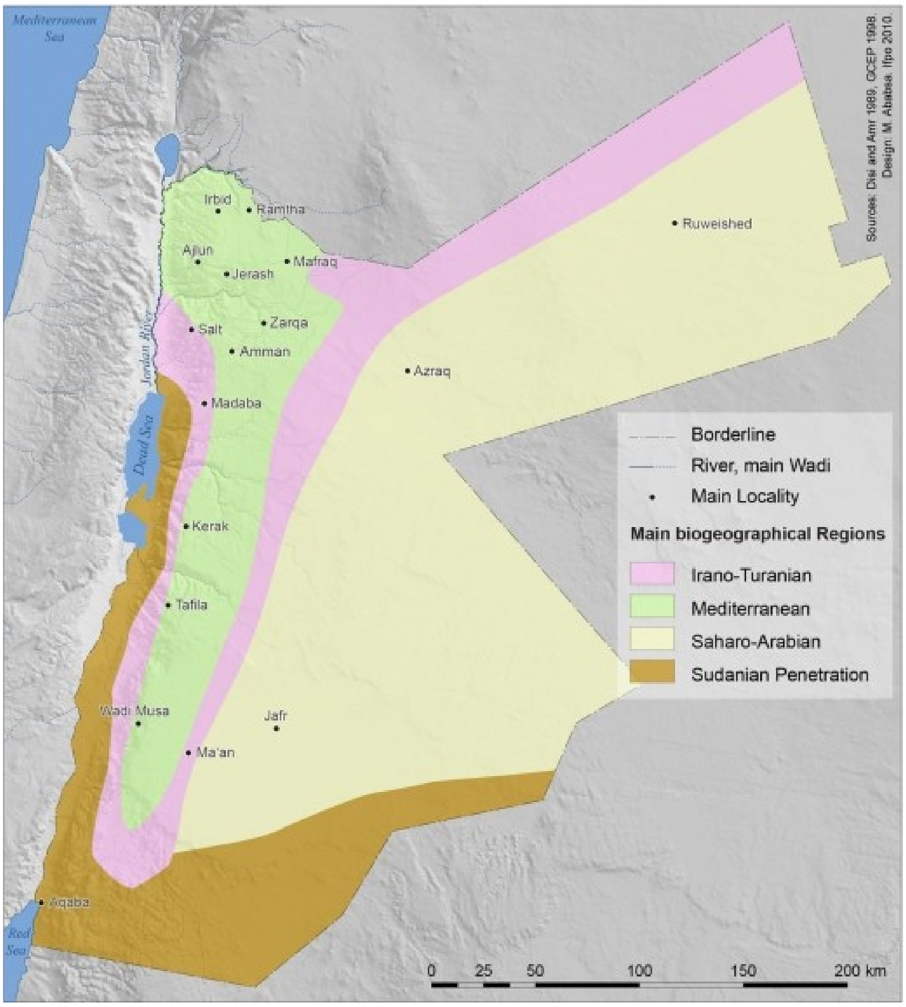

Figure 1. Biogeographical zones of Jordan, from Ababsa (2013).

and annual minimum temperature is 10-20°C (Ababsa 2013).

Climatic changes and fluctuations in Jordan

Generally, the climate is considered a Mediterranean type, with almost nine bioclimatic regions Figure 2 (Long 1957, Al-Eisawi 1985). It is characterized by a mild rainy winter and hot dry summer. Most of Jordan (90%) is composed of arid to semi-arid regions where the annual precipitation is usually very low.

Due to climate change and global warming, Jordan is suffering from a severe shift to lower rainfall means, especially in the slightly and moderately semi-arid areas that have changed towards a strongly semi-arid (Freiwan & Kadioglu 2008, Ministry of Environment 2009b). Existing climatic shifts have occurred over the past 50 years.

Annual temperature average increased since 1992 by 1.5-2 °C (Matouq *et al.* 2013). Reports of the Ministry of Environment indicated that the minimum temperature increased by 0.4-2.8 °C, and the maximum temperature increased by 0.3-1.8 °C during the period 1961-2005 (Ministry of Environment 2009a). The mean annual precipitation tended to decrease significantly by time at a rate of 1.2 mm per year (Al-Qinna 2018). The total amount of annual rain and the onset of rainfall vary greatly from year to year.

It normally starts by the end of September, but in some years, the rain delays and does not fall till the end of January (Ministry of Environment 2009a). Precipitation fluctuations affect the time of soil plowing, crop sowing, weed emergence and management. The annual average of precipitation in about 20% of the country area and does not exceed 200 mm of rain, which is the minimum level required for

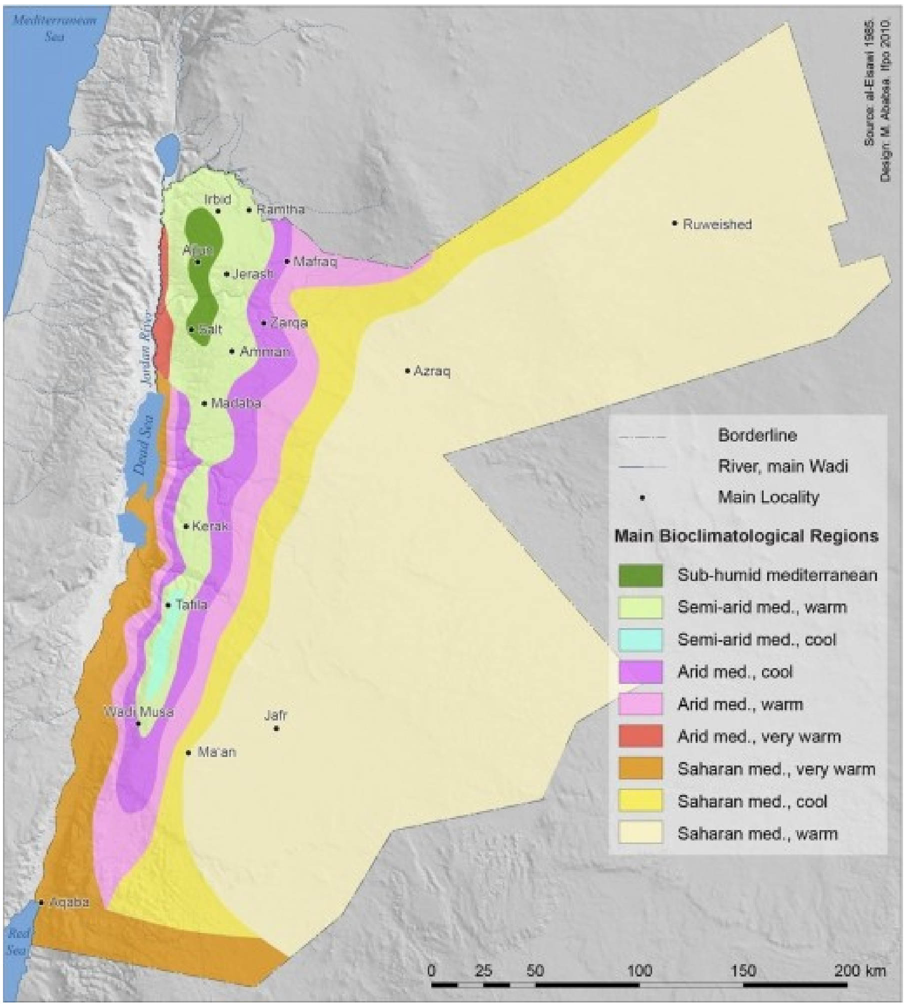

Figure 1. Main bioclimatic zones of Jordan- from Ababsa (2013).

rain-fed agriculture in the highlands.

Agricultural activities in Jordan

Crop production is concentrated in two main areas:

1. Rain-fed Irano-Turanian and Mediterranean zones in the highland, in which wheat, barley, besides other field crops such as tobacco, lentils and chickpeas are cultivated. Rain-fed olive groves are localized in areas receiving higher precipitation.

2. The Sudanian zone is characterized by having the most fertile soils in the Jordan rift valley. It encompasses Jordan valley surrounding the Dead Sea and Wadi Araba down south to Aqaba at the Red Sea, where major vegetable crops (cucumber, tomato, eggplant, peppers and melons), citrus, date palm and bananas are grown under irrigation (Helen 1989).

Irrigated crops in the highland in either the Mediterranean or Irano-Turanian zone are in areas where underground water is available, and devoted to summer vegetable crops, orchards of apple and stone fruits. No significant agriculture is present in the Saharo-Arabian zone, except in a few oases and water basins, scattered in this arid zone where barley and fodder crops are cultivated. Most of this zone is considered rangeland for grazing.

Weed distribution in cultivated fields

Variations in soil, land use, and availability of resources, ecosystem geology, altitude, soil type, and microclimate among different agro-ecosystems are expected to influence floral distribution in cultivated fields (Long 1957, Ministry of Environment 2009b). Studies on detecting weed shifts because of climatic changes are lacking in Jordan. However, we have not been witnessing serious weed shifts among different zones in Jordan since 1932 (Post & Densimore 1932, Abu-Irmaileh 2000). In addition to crop management practices, human-mediated processes (e.g., seed dispersal) play an important role in weed expansion at larger scales. It is not surprising that a weed species exists in different bio-geographical zones (Fig. 1). Moreover, certain weed species inhabiting specific bio-geographical zone, which favours their growth and development (Table 1), can extend their ranges to neighboring zones, due to weather fluctuations and to the crossings of different climatic regions into each other (Fig. 2).

This is attributed to Climatic variability in which Seasonal or long-term fluctuations (e.g., rainfall variation, temperature anomalies) may create temporary conditions favorable for weeds outside their typical zone, in addition to Ecotones/transition zones where boundaries between biogeographical zones are not strict; they often overlap, forming “ecotones” where species from both zones can establish. This is because weeds have high propagule pressure as they produce thousands of seeds, which increases the chance, that some will disperse and establish in new environments. In addition, dispersal vectors related to human activities (machinery, livestock movement, trade, and contaminated crop seed) spread weed seeds across zones.

Some weed species, which produce large number of seeds, can find suitable habitat and expand to cultivated fields in neighboring zones due to their proximity and to human activities. Farmers’ negligence or/and unawareness, rather than a response to climate change, play a significant role in weed expansion. Seeds and vegetative propagules can be easily dispersed through agricultural activities, running water and wind, movement of weed-seed-contaminated soil, or contaminated crop seeds. As an example, transporting vegetable and tobacco seedlings from seedbeds initiated in broomrapes-infested soils in Jordan valley was the main method of expanding *Orobanche* spp. infestations to clean fields in the highlands (personal observation). Even though, most troublesome weed species dominated cultivated fields in Jordan valley, they are also troublesome in irrigated fields in the Mediterranean zone that is usually colder than Jordan valley). These species are listed among the worst weeds in many countries (Holm *et al.* 1997, CABI 2011a, CABI 2011b). Weeds in cultivated fields in different regions (Table 1) represent the most common species in Jordan.

Not all listed weeds are present in a field. Most troublesome species of a genus are listed, but other species of the same genus could be found in the same field. Among the weeds existing in both Sudanian zone (Wadi Araba down south to Aqaba at the red sea and Jordan valley altitudes start from -400 m below sea level) and Mediterranean zone at much higher altitudes in the highlands include aggressive weed species such as:

Amaranthus retroflexus L., is known Redroot pigweed, redroot amaranth, rough pigweed and careless weed. It is a C4-plant, prolific seed producer and competitive in a variety of irrigated row crops and fruit tree orchards in Jordan valley, and in irrigated vegetable, apple, and stone fruit orchards in the highlands. Amaranthus species, specifically A. *retroflexus* has high water use efficiency (Weaver & McWilliams 1980, Tremmel & Patterson 1993). The growth of this weed rapidly takes over other species within their vicinity and produces a huge seed number.

Arundo donax L., Giant reed, is a difficult-to-control rhizomatous weed of Jordan valley, is expanding into irrigated farms in the highland (Abu-Irmaileh 2000). This weed could reproduce quickly by rhizomes and seeds. It invades wetlands around water bodies and irrigation canals and creeps into cultivated fields, and alters habitats towards dense, monotypic stands up to 3 m tall.

Cynodon dactylon (L.), Bermuda grass, is a serious invading weed; very widely distributed throughout the world in almost all soil types especially in fertile soil. It reproduces by seeds, stem cuts and rhizomes. It is most common weed

Table 1. Most troublesome weed species in Sudanian, Mediterranean, and Irano-Turanean zones.

Sudanian	Mediterranean	Irano-Turanean
Amaranthus retroflexus	*Amaranthus blitoides*	*Alkanna strigos*
Ammi majus	*Amaranthus retroflexus*	*Astraagalus spinosus*
Arundo donax	*Aanthemis palestina*	*Calenula arvensis*
Beta vylgaris	*Avena sterilis*	*Centaurea eryngioides*
Chenopodium murale	*Bromus tectorum*	*Cephalria syriaca*
Convolvulus arvensis	*Cardaria draba*	*Chorispora purpurascens*
Cuscuta campestris	*Cynodon dactylon*	*Echium judaeum*
Cyperus esculentus	*Cuscuta campestris*	*Erucaria hispanica*
Cynodon dactylon	*DIplotaxis erucoides*	*Fumaria densiflora*
Glycerrhiza glabra	*Hirschfeldia incana*	*Geranium tuberosum*
Malva nicaeensis	*Hypericum triquetrifolium*	*Gladiolus segetum*
Orobanche crenata	*Lactuca serriola*	*Hordeum glaucum*
Orobanche ramosa	*Onobrychis crust-galli*	*Hyoscyamus reticulatus*
Prosopis farcta	*Orobanche ramosa*	*Ononis antiquorum*
Portulaca oleracaae	*Onopordum alexandrinum*	*Poa sinaica*
Solanum elaeagnifolium	*Salvia syriaca*	*Silene conoidea*
Sorghum halepense	*Sinapis arvensis*	*Trigonella arabica*
Tribulus terrestris	*Tribulus terrestris*	*Texiera glastifoliaa*

in alfalfa fields, fruit trees as well as uncultivated lands (Holm *et al.* 1977, Abu-Irmaileh 2000).

Cyperus esculentus, the Tiger nut or Yelleiw nutsedge, produces mainly by tubers, and extremely difficult to eradicate. It can quickly regenerate from a single tuber and forms dense colonies, which suffocates other plants species in its vicinity (Holm *et al.* 1977, Abu-Irmaileh, 2000, Dodet *et al.* 2008).

Prosopis farcta, the Syrian mesquite, is one of most dominant and troublesome species in Jordan valley. It is spreading at lower and higher altitudes in the highlands. It is a troublesome shrub with a branched root system, which penetrates as deep as 20 meters below soil surface. It infests cultivated fields and waste areas in Jordan valley and extends through the Mediterranean and the Iran-Turanian zone. It can survive difficult weather and soil conditions (including saline soil). However, *Prosopis* genus is treated as one of the world's worst invasive plant species (CABI 2011b).

Different species of *Prosopis*, namely, *P. juliflora* and *P. chinensis* (Salam in Arabic) were introduced as trees and shrubs for fencing orchards in Jordan valley, are expanding into higher altitudes. *P. juliflora* trees rapidly form dense thorny thickets and block irrigation channels, obstruct roads, reduce accessibility to pasture, croplands, and water sources in many countries. It is considered a serious invasive species in many parts of Eastern Sudan and Ethiopia (Weber 2003, Babiker 2006, Hoshino *et al.* 2012, Mehari 2015).

Sorghum halepense, the Johnsongrass, is a perennial grass with a worldwide distribution. Its extensive spreading rhizome and shoot system and high rate of seed production make it extremely invasive and difficult to eradicate (Labrada 1994). This species is a C_4-plant and shows correspondingly rapid growth under warm and hot conditions (Holm *et al.* 1977). *S. halepense* infests irrigated fields in Jordan valley and many irrigated orchards and vegetable field crops in the highlands at altitudes 1200 m above sea level in the south (For example, Shoubak area, which receives annual snow much earlier than other highlands, a much colder climate than Jordan valley).

Solanum elaeagnifolium, the Silverleaf nightshade, is a deep-rooted noxious perennial weed, which reproduces by both seed and vegetative propagules, is poisonous plant to grazing animals (Mas & Lugo-Torres 2013). It was introduced to many countries around the world as a crop seed contaminant in soil and crops (Holm *et al.* 1997, EPPO 2007). This weed had invaded ecosystems in Jordan valley and in rain-fed in the highlands. Farmers in Jordan face difficulties controlling *Solanum elaeagnifolium* due to its deep and extensive root system, high seed and vegetative reproductive capacity, adaptability to poor soils, and limited effectiveness of mechanical and chemical control measures. FAO formulated a technical cooperation programme (TCP)-project to manage this weed in several countries in the Middle East region (Gbèhounou 2013).

Cuscuta campestris Yunk. field dodder, is a serious parasitic weed around the world and in Jordan. It has wide host range of crops and weeds. Seeds germinate without a need for a germination stimulant provided by the host. Some seeds have a hard coat, which requires gradual degradation or scarification to germinate. Once germinated, light, and a relatively high temperature of 25°C, are needed for the parasite to coil and form haustorium (Holm *et al.* 1997, Costea & Tardif 2006), which connect to the host phloem, enabling the parasite to become a powerful sink for metabolites, and totally dependent on the host for growth and survival, causing a severe drain on host resources, preventing normal host development and retarding crop production.

Orobanche ramose, the Branched broomrape or Hemp broomrape, is the main species, which infests large areas of host crops, including tobacco, many cucurbit, legume, and eggplant crops in both irrigated and rain-fed areas. It also infests many weed species. Each plant produces enormous number of very light seeds which can be easily carried by wind, contaminated crop seeds, soil, machinery and expand its range within and outside the country. *Orobanche* is among weeds that are verbuty difficult to eradicate. *Orobanche* species are listed as prohibited and/or subject to quarantine, in virtually all countries with developed plant quarantine systems (USA 2008, USDA-NRCS 2008). Quarantine regulations in most countries should be enforced to ensure effective prevention of further spread.

Other parasitic plants exist in Jordan, including *Cistanche tuberosa, Loranthus acaciae, Osyris alba, Thesium humile,* and *Viscum cruciatum*, and cause severe harm to their host plants (Qasem 2022). These parasitic plants are not widespread in Jordan (Qasem 2022). Weed species listed in Table 1 are the most common, but other species can be competitive, troublesome (thorny, poisonous or serious contaminant of agricultural goods) when present in large populations in either zone.

Farmer field schools (FFSs)

According to Food and Agriculture Organization, FFSs is defined as" an approach based on people-centred learning. Participatory methods to create an environment conducive to learning: the participants can exchange knowledge and experience in a risk-free setting".

Necessity of farmers' capacity building in developing countries to plan for better weed management strategies

Many of the developed weed technologies have not been effectively disseminated to farmers in developing countries due to technical, institutional and socio-economic constraints; including lack of reliable research and extension, poor knowledge of the biological and ecological features of weeds, which make them invasive and competitive. Although new technological discoveries are continuing, besides that individual control options may lead to good weed control and increase crop yields, none of the currently available control measures has proven to be completely effective. Weed infestations of local, as well as the new invasive species keep threatening the livelihood of farmers.

FFSs are effective, community-based, non-formal adult education programs (Labrada 2004). They train and empower farmers through hands-on learning to understand ecological principles and promote Integrated Weed Management. FFSs encourage farmer groups to compare local practices with holistic, integrated crop production approaches, ultimately leading to better, more profitable crop production and improved livelihoods.

Studies focusing on climate change primarily address plant physiology, yet its impact on integrated weed management (IWM) in mixed fields needs more research. Inevitable weed composition shifts demand investigation into IWM practices—like crop choice, herbicide-resistant crops/weeds, and sowing time—to build better strategies.

Farmers in developing nations lack skills and affordable equipment for chemical control. While preventing new weed introductions is hard, raising awareness and vigilance is crucial. Quarantine and community awareness are vital to contain serious migratory weeds, exemplified by the successful containment of *Striga asiatica* in the USA (Eplee 1992). Farmers require training in adaptive IWM strategies to overcome increasingly complex weed problems, considering their socioeconomic status.

Introducing FFSs in Jordan and their role in weed management in various farming systems

Farmers have limited access to information and advisory services (Luqman *et al.* 2024). Most farming communities in Jordan are characterized by being smallholders or subsistent farmers. Famers' attitude towards weeds varies as being aggressive pests having negative impact on their productivity in small farming systems, or not as harmful in subsistent farming situations. However, all farmers appreciate any affordable technology, which improves their living conditions. Thus, weed management should be adapted to the existing socioeconomic conditions of the farmer. The adaptation and dissemination of appropriate weed management practices are most challenging, taking into consideration the specific socio-economic characteristics of farming systems.

Prior to the introduction of FFSs, extension agents were trained in weed science by exposing them to short courses in cooperation with the Ministry of Agriculture. Researchers and trained extension agents used to hold field-day-demonstrations on most promising research results and technologies to expose invited groups of farmers in cooperating farmer field in each farming area. However, there were no serious follow up for testing farmers' applications of the demonstrated results.

In Jordan, more than 85% of the government extension agents were trained through the Food and Agriculture Organizations' (FAO) Regional Integrated Pest Management (IPM) Program in the Near East started its activities in Jordan (Labrada 2004) considering the integration of pest and disease management with different crop production practices. Using ecology-based IPM approaches to promote sustainable management of pests, about 170 FFSs have been established by the National Agricultural Research Center (NARC) in Jordan since its inception; training approximately 2,400 farmers who started organizing themselves in order to carry out field experiments, train other farmers, and interact effectively with research and extension.

Effective weed management in Jordan required a community-based integrated approach to improve the dissemination of knowledge and skills by using FFSs, in which farmers participate in discussing the problems they encounter from weeds and share their views on best affordable practices to get rid of harmful weeds. Many of the technologies are either unavailable, or beyond farmers' affordability. Therefore, the diverse biophysical and socio-economic challenges faced by farming communities are discussed and analysed through FFSs meetings, suggesting best possible utilization of farm resources and farmer's capabilities in order to avoid or manage risks that would otherwise have serious consequences in the farming system (Abu-Irmaileh & Labrada 2006).

FFSs have been designed to help farmers learn the principles and practices of integrated management of weeds including the parasitic broomrapes, *Orobanche*; and serve as an essential part of a long-term and dynamic farming systems approach for sustaining and enhancing agricultural productivity (Abu-Irmaileh 2004). FFSs provided an important entry point for enhancing farmers' understanding of the ecological and agronomic principles of weed management within their farm management. FFSs enhanced farmers' understanding the suitable integrated weed management in order to increase their productivity and improve their living conditions.

To accomplish a successful participatory approach for weed management, local research facilities should be staffed with trained research and extension workers (Abang *et al.* 2007). Capacity building in weed management started with 27 extension agents from various agricultural areas. The curriculum of training was developed on integrated direct and indirect weed management means. Each extension agent became a trainer of farmer in the served area using FFSs approach.

The concept of FFSs was applied for management of broomrapes, *Orobanche* spp., parasitizing tomato and other vegetables. Possible means for reducing broomrape parasitism included hand and mechanical removal of *Orobanche* and its weed-hosts, rotation with non-host, trap and catch crops, soil solarization for six weeks using black plastic sheets during the hottest months (Abu-Irmaileh 1984, Abu-Irmaileh 2003, Abu-Irmaileh 2004), breeding for resistant crops against parasitic weed (Rubiales *et al.* 2006) chemical and biological weed control (Kroschel & Klein 2004, Martin *et al.* 2018) besides planting herbicide-resistant crops (Kotoula-Syka & Economou 2005).

Leading farmers applied the affordable effective means for *Orobanche* management who were able to disseminate gained knowledge around his region. FFSs enhanced farmers' understanding of the ecological principles of good *Orobanche* management. Running FFSs helped farmers learn the principles and practices of integrated *Orobanche* and other weed management as an essential part of any long-term and dynamic strategy for sustaining and enhancing agricultural productivity.

Most appreciated strategy of *Orobanche* management was solarizing the soil by covering planting rows with black plastic sheets (BP) for six weeks during summer. Drip irrigation system is placed under tarp for moistening the soil 2-3 times during solarization period. BP tarp is left in place over planting rows as black tarp for the rest of the season. Holes are made at proper distances for planting the crop seedlings.

Elevated heat during solarization to a depth of 10-15 cm under tarp raised soil temperature enough to kill imbibed weed seeds and other active soil living inhabitants (Barakat 1987, Abu-Gharbieh *et al.* 1991, Lamont 1999). Vegetable yields were increased by 2-3 folds. In addition to its efficiency in reducing weed infestation, and controlling many of the soil born pests, soil solarization improved the solubility of nutrients and improved nutrient uptake by the crop roots (Barakat 1987, Al-Kalaielah 1988, Stapleton & DeVay 1995, Elmore *et al.* 1997).

Soil solarization technique was generally practiced among all farmers in Jordan valley for controlling weeds as well as the *Orobanche*, in almost all vegetable production area under plastic tunnels and houses (Abu-Irmaileh 1991). Weed management in the upland depends on private agricultural dealers who promote their products, the advice of the academic weed scientists and the staffed FFSs weed management scientists and extension agents.

Difficulties facing FFSs in weed management due to climate changes and fluctuations in Jordan

Changes in climate may bring about extended wetter or drier seasons. Early weeding may be difficult during shorter periods of suitable conditions once the fields become wet. Weed removal by tillage equipment is applicable between row crops with suitable row widths. Weeds, within crop rows and closer to crop plants, escape removal, so should be controlled;

otherwise, crop losses are expected (Melander *et al.* 2012). Repeated operations are necessary for effective weed control. However, several passes of heavy equipment led to soil compaction (Smith *et al.* 2011), increased soil erosion, and leaching of plant nutrients (Ahlgren 2004). Low input farming systems will be more negatively impacted compared to intensive farming, as the affordability of farmers to cope with drought and heat stress is much less than those in intensive farming systems. Weed toll is heavy in this system due to the lack of proper weed management. It is well known that the prevailing environmental conditions have a large impact on the effectiveness of various practices of weed management, including cultural, chemical, and integrated crop management.

Manual weeding is still practiced where labour is cheap, especially in small landholdings and in subsistent farming systems. Weeds are removed by simple tillage tools or tools drawn by animals. However, the immediate availability of labour before the weeds cause economic losses to crops is a critical factor in the success of this method (Shad 2015). However, this method is usually inconvenient, uneconomical, and unfeasible in larger farms (Donald 2000, Rao *et al.* 2007).

Effective results of chemical weed control depend on the recommended herbicide application at the proper weed growth stage during the best possible set of environmental conditions. If changes in climatic factors bring about drought, heat and water stress, and low soil moisture, weeds develop thicker cuticle with increased leaf pubescence, resulting in subsequent reductions in herbicide entry into the leaf and/or translocation to target sites. Herbicide rates should be adjusted to get the most effective actions, during the prevailing climatic factors. Higher rates of application may be necessary, or certain adjuvants could be added to enhance the efficacy of control. Higher rate of application or repeated application of the same herbicide result in weed shifts towards species that were not normally controlled by the recommended application.

Drift hazard from application of these herbicides, and lack of safety precautions are among the shortcomings of this situation. Farmers suffer from the lack of knowledge about herbicide residues. FFSs make farmers aware of herbicide-tolerant or herbicide-resistant weeds. Besides, certain weed species develop tolerance or resistance to herbicides having similar mode of action and selectivity pattern. Solaimalai *et al.* (2004) reported that after few years of 2,4-D application, grassy weeds appeared. In addition to the more troublesome grassy weeds, Abu-Irmaileh *et al.* (2015) found new tolerant 2,4-D broadleaf weed species from the family Caryophyllaceae became dominant after the continuous application of 2,4-D in grain fields in Jordan. Most farmers in Jordan rely on private cooperatives that have herbicide-spraying equipment.

Spraying is sometimes delayed due to a wet weather, resulting in crop injury and ineffective weed management. To overcome this situation, spraying equipment and the proper herbicide should be made available at the proper growth stage. Current herbicides should be continuously replaced with others having different modes of action to control the herbicide-resistant weeds (Kao-Kniffin *et al.* 2013). Farmers will also be faced with fewer choices of suitable herbicides to control weeds, as the discovery of new herbicides has been drastically reduced in recent years (Duke 2012). Jordan's limited agrochemical market restricts chemical weed control options. Climate change awareness is crucial, as drought and heat stress reduce the efficacy of pre-emergent soil herbicides, which need moisture for activation (Zhang *et al.* 2005).

Slower microbial degradation under dry conditions can extend herbicide persistence, while warmer, sunnier days increase photodecomposition and volatility (Brown 2008). Conversely, a more humid, warmer climate can shorten persistence (Bailey 2004). Persistent herbicides like sulfonylurea and triazine can harm subsequent sensitive crops (Zimdahl 2007). Additionally, elevated CO_2 stimulates photosynthesis, making rhizomatous perennial weeds harder to control (Patterson 1995).

Role of FFSs in weed management under climate change in different ecosystems in Jordan

A1. Subsistent farming system : Over 85% of land holdings in Jordan are considered small farms, with areas not exceeding 10 hectares. However, holdings in subsistent farming in Jordan do not exceed one hectare, characterized by mixed cropping that limits chemical weed control. Weeding is mostly carried out by family members or cheap workhands. Weeds are left to grow until they are easily grasped and removed by hand, small weeding tools, and/ or animal-driven local plows. Most weeds reach flowering prior to their removal. After harvest, crop remains and weed leftovers are plowed under as part of traditional practices where viable seeds may be added to the soil, increasing future infestations. Farmers traditionally use weed-contaminated fresh manure, aggravating weed infestation and leading to crop losses despite selective manual weeding due to competition and increased pests (personal observation). Lacking knowledge and capital for proper herbicide use, subsistence farmers face challenges. A successful Farmer Field School (FFS) strategy involved pre-plant composting of fresh manure under tarp (BP) for six weeks, often during summer soil solarization. Elevated soil heat from solarization combined with heat from manure fermentation effectively killed imbibed weed seeds, diseases, insects, and nematodes to a depth of 10–15 cm (Barakat 1987, Al-Kalaielah 1988, Abu-Gharbieh *et al.* 1991). This technique controlled in-row weeds, significantly improved crop yields, and was adopted widely, with increased yields making the plastic tarp affordable (Abu-Irmaileh & Abu Rayyan 2006, Abu-Irmaileh & Abu Rayyan 2007).

A2. Subsistent rain-fed farming system: Farmers follow a two-year rotation of cereals - summer legumes and/or summer vegetables (cucurbit crops). Most farms have mixed cropping. Olives and stone fruits are found in small areas within the farm. Weeds are always plowed after rain and prior to planting cereals or summer vegetables. In years of drought, the farm can be fallowed for one year. No further weeding is carried out. Crops are selectively harvested manually. Yields are normally higher if precipitation is enough to allow good growing seasons. Farm animals are allowed to graze the remains of the cropped area.

B. Weed management in small farming systems:

B1. Irrigated farming system: Over 85% of land holdings in Jordan are considered small-scale farms, with areas not exceeding 10 hectares. Most irrigated farms in Jordan valley and lowland areas follow soil solarization during the hottest period of the year (June–September). Vegetable crops are commonly planted under plastic tunnels and plastic houses (protected crops) in solarized farms. Soil solarization provides effective soil-pest control, including weeds, especially if crop rows are tarped with BP sheets during the solarization period for six weeks prior to planting (Abu-Irmaileh 1994, Abu-Irmaileh & Saghir 1994, Abu-Irmaileh 2003). This technique provided good control of weeds, pathogens, and parasitic broomrapes. Rarely weeds appear in the solarized planting rows. Weeds appearing between plastic tunnels or plastic houses are hand weeded or controlled mechanically. General herbicides (e.g. glufosinate, glyphosate or paraquat) are applied in few farms. Herbicide drift causes crop injuries if carelessly applied. In some cases, vegetable crops and fruit trees are planted outside plastic tunnels. Tarping (covering with BP) the planting rows of vegetables, fruit trees or vines provided good weed control in the planting row under tarp (Abu Rayyan *et al.* 2011). Weeds appearing between the tarped rows are then removed manually or ploughed under using animal-driven local ploughs. At the end of the season, the unusable plastic sheets and plastic pipes are collected for recycling. Limited herbicides and poor application knowledge cause crop damage from drift and carryover, but Farmer Field Schools (FFSs) are helping.

B2. Non-irrigated small farming system: Grain crops and pulses dominate this system, with orchards making up about 15% of the area. Planting follows autumn rains (November–December) after pre-plant plowing removes initial weeds. For decades, 2, 4-D has been the sole chemical for broadleaf weed control in grain crops in Jordan. Continuous use has caused weed shifts, leading to the dominance of 2, 4-D-resistant broadleaf weeds and increased grassy weeds like wild oat and rye grass. Abu-Irmaileh *et al.* (2015) reported new tolerant species from the Caryophyllaceae family becoming prevalent.

Orchard weed control primarily uses plows, with minimal herbicide use due to limited market availability. Farmer Field Schools (FFSs) now educate farmers on herbicide-tolerant/resistant weeds and promote herbicide and crop rotations to manage new infestations.

C. Large farming system: Most farms are located in rain-fed areas and are usually planted to grain crops. The only weed management is carried out by spraying 2, 4-D for controlling broadleaf weeds. Most farmers rely on private cooperatives that have large sprayers. However, spraying is not done at the proper growth stage. Crop injury is commonly noticed. FFSs make farmers aware of herbicide-tolerant or herbicide-resistant weeds. Herbicide rotations and /or crop rotations were advised to reduce the infestation of new weed problems.

The repeated applications of the same herbicide caused a shift towards the dominance of weedy grasses and tolerant 2, 4-D weed species. Large farms with a source of irrigation (artesian wells) are planted to either vegetable under plastic tarps, or fruit trees. Weeds are mechanically removed between planted rows, in addition to manual weeding within the vicinity of the crop plants. Weed toll is heavy in this system due to the lack of proper weed management. General herbicides such as glyphosate and paraquat have been the main herbicides sold in the Jordanian market. Drift hazard from application of these herbicides, and lack of safety precautions are among the shortcomings of this situation. Farmers usually suffer from the lack of knowledge about herbicide fates and residues. FFSs make farmers aware of herbicide-tolerant or resistant weeds. Only a few extension agents received proper training on chemical weed control. FFSs help many leading farmers to start to import more appropriate herbicides to suit their crops. Private agricultural companies promote their herbicidal formulations. Herbicide rotations and /or crop rotations were advised to reduce the infestation of new weed problems.

CONCLUSION

In conclusion, weed management continues at the same pace in any ecosystem if no alarming problematic weeds arise. Different new migratory weed species continue to pass unnoticed and expand to nearby farms. Monitoring field scouting and close attention could not be carried out by each farmer, but was aided by experienced extension agents through FFSs. In view of the impact of climatic changes on agroecosystems, weed science specialists at extension services in Jordan and other developing countries should be made aware of the worst weed species (invasive weeds, noxious weeds, and those highly adaptive to climate change), trained to gain knowledge about their biology and ecology, to closely scout fields and to report their findings to proper authorities of the community in order to start management actions as early as possible. They should also use FFSs to educate local farmers on the effective integrated weed management strategies. Other findings about difficulties in managing the already existing weeds should be challenged by researchers. A concerted effort between farmers and weed scientists towards building a participatory approach to challenge weed management is required, and FFSs are still in need to continue with capacity building in weed management.

REFERENCES

Ababsa M (2013) Atlas of Jordan: History, Territories and Society. *Nouvelle édition [en ligne]*. Beyrouth: Presses de l'Ifpo (généré le 14 octobre 2020). https://doi.org/10.4000/books.ifpo.4849.

Abang MM, Bayaa B, Abu-Irmaileh BE, Yahaoui A (2007) A participatory farming system approach for sustainable broomrape (Orobanche spp.) management in the Near East and North Africa. *Crop Protection*, 26(12), 1723–1732. https://doi.org/10.1016/j.cropro.2007.03.005.

Abu-Gharbieh WI, Saleh H, Abu-Blan H (1991) Use of black plastic for soil solarization and post-plant mulching; Amman, Jordan. 229–242.

Abu-Irmaileh BE (1984) Effect of planting flax on the subsequent infestation of tomato by *Orobanche ramosa* L. In: Parker C, Musselman LJ, Polhill RM and Wilson AK, editors; ICARDA, Aleppo, Syria. 250–255.

Abu-Irmaileh BE (1991) Soil solarization controls broomrapes (*Orobanche* spp.) in host vegetable crops in the Jordan Valley. *Weed Technology*, 5(3), 575–581. https://doi.org/10.1017/S0890037X00027366.

Abu-Irmaileh BE (1994) Weed control by soil solarization in newly established fruit-trees. 21B:207–219.

Abu-Irmaileh BE (2000) *Weeds of cultivated fields*. Amman: Publications of the University of Jordan.

Abu-Irmaileh BE (2003) Soil solarization. In: Labrada R, editor; FAO, Rome. *FAO Plant Production and Protection*. 211–222.

Abu-Irmaileh BE (2004) Orobanche in food legumes in the Near East and North Africa. In: Dahan R and El Mourid M, editors; Rabat, Morocco. ICARDA, INRA, FAO. 19–31.

Abu-Irmaileh BE, Labrada R (2006) The problem of *Orobanche* spp. in Africa and Near East. *FAO Plant Production and Protection Division-IPM-Weed Management*.

Abu-Irmaileh BE, Saghir AR (1994) Components of successful weed management with special reference to vegetable growers in the Near East. *FAO Plant Protection Bulletin*, 42(4), 191–200.

Abu-Irmaileh BE, Syouf M, Al-Fakhori S (2015) 2,4-D tolerant new weed species of Caryophyllaceae plant family. *Crop Research*, 49, 79–85.

Abu-Irmaileh BE, Abu Rayyan AM (2006) Pre-plant manure composting controls hemp broomrape on tomato. *Jordan Journal of Agricultural Sciences*, 2(2), 54–163.

Abu-Irmaileh BE, Abu Rayyan AM (2007) Vegetable crop tolerance to pre-plant composting of organic matter Jordan. *Journal of Agricultural Sciences*, 3, 429–439.

Abu Rayyan AM, Shatat FA, Abu-Irmaileh BE (2011) Response of fruit trees to composting of animal manures in the tree line. *Journal of Food Agriculture and Environment*, 9(3), 492–495.

Ahlgren S (2004) Environmental impact of chemical and mechanical weed control in agriculture: a comparing study using life cycle assessment (LCA) methodology. Gothenburg, Sweden: *The Swedish Institute for Food and Biotechnology*.

Al-Eisawi DM (1985) Vegetation of Jordan. In: Hadidi A, editor. *Studies in the History and Archaeology of Jordan, I*. Amman, Jordan: Department of Antiquities. 45–56.

Al-Eisawi DM (1996) *Vegetation of Jordan*. Cairo, Egypt: UNESCO, Regional Office for Science and Technology for the Arab States.

Al-Kalaielah R (1988) Effect of soil solarization using different thicknesses of transparent polyethylene on cucumber grown in plastic houses in the Jordan valley. Amman, Jordan: *University of Jordan*. 118 p.

Al-Qinna MI (2018) Analyses of Climate Variability in Jordan using Topographic Auxiliary Variables by the Cokriging Technique. *Jordan Journal of Earth and Environmental Sciences*, 9, 67–74.

Allen JM, Bradley BA (2016) Out of the weeds? Reduced plant invasion risk with climate change in the continental United States. *Biological Conservation*, 203, 306–312.

Amare T (2016) Review on Impact of Climate Change on Weed and Their Management. *American Journal of Biological and Environmental Statistics*, 2(3), 21–27. https://doi.org/10.11648/j.ajbes.20160203.12.

Babiker AGT (2006) Mesquite (*Prosopis* spp.) in Sudan: history, distribution and control. *Problems Posed by the Introduction of Prosopis spp. in Selected Countries*. Rome, Italy: FAO.

Bailey SW (2004) Climate change and decreasing herbicide performance. *Pest Management Science*, 60(2), 158–162.

Baker HG (1965) Characteristics and modes of origin of weeds. In: Baker HG and Stebbins GL, editors. *The genetics of colonizing species*. New York: Academic Press. 147–168.

Barakat R (1987) Comparative effect of different colors of polyethylene tarping on soilborne pathogens [M. Sc.]. Amman: *University of Jordan*. 82 p.

Beaumont LJ, Gallagher RV, Leishman MR, Hughes L, Downey PO (2014) How can knowledge of the climate niche inform the weed risk assessment process? A case study of *Chrysanthemoides monilifera* in Australia. *Diversity and Distributions*, 20, 613–625. https://doi.org/10.1111/ddi.12190.

Bleier JS, Jackson RD (2007) Manipulating the quantity, quality, and manner of C addition to reduce soil inorganic N and increase C4: C3 grass biomass. *Restoration Ecology*, 15(4), 688–695.

Breitsameter L, Bürger J, Peters K, Edler B, Peters K, Gerowitt B, Steinmann H (2014) Climate change impact research on arable weeds – data, methods and applications at various scale levels. In: *26th German Conference on Weed Biology and Weed Control*. Braunschweig, Germany, 123–132.

Bridges DC (1992) *Crop Losses Due to Weeds in the United States*. Weed Science Society of America, Champaign, Ill., USA.

Brown SM (2008) Drought impact on weed management. University of Georgia College of Agricultural and Environmental Sciences Cooperative Extension. Extension bulletin.

Byrd JDJ, Maddox V, Westbrooks R (2018) Itchgrass. Mississippi State University Extension.

CABI (2011a) Invasive Species compendium online data sheet. *Cynodon dactylon* (Bermuda grass). CAB International, Wallingford, UK.

CABI (2011b) *Invasive species compendium. Detailed coverage of invasive species threatening the livelihoods and the environment worldwide*. CAB International, Wallingford, UK.

Chandrasena N (2009) How will weed management change under climate change? Some perspectives. *Journal of Crop and Weed*, 5(2), 95–105.

Clements DR, Ditommaso A (2011) Climate change and weed adaptation: can evolution of invasive plants lead to greater range expansion than forecasted. *Weed Research*, 51, 227–240. https://doi.org/10.1111/j.1365-3180.2011.00850.x.

Costea M, Tardif FJ (2006) The biology of Canadian weeds. 133. *Cuscuta campestris* Yuncker, *C. gronovii* Willd. ex Schult., *C. umbrosa* Beyr. ex Hook., *C. epithymum* L. and *C. epilinum* Weihe. *Canadian Journal of Plant Science*, 86(1), 293–316. https://doi.org/10.4141/P04-077.

Crossman ND, Bryan BA, Cooke DA (2011) An invasive plant and climate change threat index for weed risk management: integrating habitat distribution pattern and dispersal process. *Ecological Indicators*, 11(1), 183–198. https://doi.org/10.1016/j.ecolind.2008.10.011.

Daehler CC (2003) Performance comparisons of co-occurring native and alien invasive plants: implications for conservation and restoration. *Annual Review of Ecology, Evolution, and Systematics*, 34, 183–211. https://doi.org/10.1146/annurev.ecolsys.34.011802.132403.

Dodet M, Petit RJ, Gasquez J (2008) Local spread of the invasive *Cyperus esculentus* (Cyperaceae) inferred using molecular genetic markers. *Weed Research*, 48(1), 19–27.

Donald WW (2000) Alternative ways to control weeds between rows in weeded check plots in corn (*Zea mays*) and soybean (*Glycine max*). *Weed Research*, 40(1), 36–44. https://doi.org/10.1111/j.1365-3180.2008.00606.x.

Duke SO (2012) Why has no new herbicide modes of action appeared in recent years? *Pest Management Science*, 68(4), 505–512. https://doi.org/10.1002/ps.2333.

Elmore CL, Stapleton JJ, Bell CE, DeVay JE (1997) *Soil Solarization: A Non-pesticidal Method for Controlling Diseases, Nematodes, and Weeds*. University of California Division of Agriculture and Natural Resources, Oakland, California.

Eplee ER (1992) Witchweed (*Striga asiatica*): an overview of management strategies in the USA. *Crop Protection*, 11(1), 3–7.

EPPO (2007) *Solanum elaeagnifolium*. Datasheets on Quarantine Pests. *EPPO Bulletin*, 37(2), 236–245.

Freiwan M, Kadioglu M (2008) Climate variability in Jordan. *International Journal of Climatology*, 28(1), 69–89. https://doi.org/10.1002/joc.1512.

Gbèhounou G (2013) TCP/RAB/3301. Management of the invasive plant *Solanum elaeagnifolium* in the Near East. Food and Agriculture Organization of the United Nations, Rome.

Gratani L (2014) Plant phenotypic plasticity in response to environmental factors. *Advances in Botany*, 2014, 1–17. https://doi.org/10.1155/2014/208747.

Hall AE, Allen LHJ (1993) Designing cultivars for the climatic conditions of the next century. In: Buxton DR, Shibles R, Forsberg RA, Blad BL, Asay KH, Paulsen GM, Wilson RF (Eds). *International Crop Science I*. Crop Science Society of America, Madison, Wisconsin, 291–297.

Helen CM (1989) Jordan: A Country Study: Agriculture. In: *Jordan: A Country Study*. Library of Congress, Washington D.C.

Hobbs RJ, Huenneke LF (1992) Disturbance, diversity, and invasion: implications for conservation. *Conservation Biology*, 6(3), 324–337. https://doi.org/10.1046/j.1523-1739.1992.06030324.x.

Holm LG, Doll J, Holm E, Pancho J, Herberger J (1997) *World Weeds: Natural Histories and Distribution*. John Wiley Sons Inc, New York, USA.

Holm LRG, Plucknett DL, Pancho JV, Herberger JP (1977) *The World's Worst Weeds. Distribution and Biology*. University Press of Hawaii, Honolulu, USA.

Hoshino H, Karamalla MA, Abd elbasit M, Manayeva K, Yoda K, Suliman M, Ibrahim M, Nawata H, Yasuda H (2012) Evaluating the invasion strategic of Mesquite (*Prosopis juliflora*) in Eastern Sudan using remotely sensed technique. *Journal of Arid Land Studies*, 22(1), 1–4.

Kao-Kniffin J, Carver SM, DiTommaso A (2013) Advancing weed management strategies using metagenomic techniques. *Weed Science*, 61(2), 171–184. https://doi.org/10.1614/WS-D-12-00114.1.

King TA, Norsworthy JK, Butts TR, Fernandes SB, Drescher GL, Avent TH (2025) Effect of Palmer amaranth (*Amaranthus palmeri*) time of emergence on furrow-irrigated rice yields and weed seed production. *Weed Science*, 73(1), 1–8. https://doi.org/10.1017/wsc.2024.102.

Kotoula-Syka E, Economou G (2005) Use of herbicide resistant crops in Greece for control of Orobanche and other weeds. In: Proceedings of the Joint Working Groups and MC meeting of COST Action 849, Broomrape Biology, Control and Management, September 15-17, 2005. Reading University, UK, 35–36.

Kroschel J, Klein O (2004) Biological control of Orobanche spp in the Near East and North Africa by inundative releases of the herbivore *Phytomyza orobanchia*. In: Dahan R, El Mourid M (Eds). Proceedings of a Conference on Parasitic Weeds. ICARDA, INRA, FAO, Rabat, Morocco, 55–66.

Labrada R (1994) *Sorghum halepense* (L.) Pers. In: Labrada R, Caseley JC, Parker C (Eds). *Weed Management for Developing Countries*. Food and Agriculture Organisation of the United Nations, Rome, Italy, 81–89.

Labrada R (2004) The IPM approach and participatory training for management of parasitic weeds. In: Dahan R, El Mourid M (Eds). Proceedings of a Conference on Parasitic Weeds. ICARDA, INRA, FAO, Rabat, Morocco, 72–75.

Laitinen RAE (2024) Importance of phenotypic plasticity in crop resilience. *Journal of Experimental Botany*, 75(3), 670–673. https://doi.org/10.1093/jxb/erad465.

Lamont WJ (1999) The use of different colored mulches for yield and earliness. In: Proceedings of the New England Vegetable and Berry Conference. Sturbridge, Mass., 299–302.

Li P, An Z, Xu N, Li J, Li Q, He C (2025) Phenotypic plasticity and stability in plants: Genetic mechanisms, environmental adaptation, evolutionary implications, and future directions. *Plant, Cell Environment*, 48(8), 5847–5860. https://doi.org/10.1111/pce.15566.

Long G (1957) *The Bioclimatology and Vegetation of East Jordan*. UNESCO/FAO, Rome.

Low T, Booth C (2007) The weedy truth about biofuels. *Invasive Species Council*. Retrieved from www.invasives.org.au.

Luqman M, Ashraf A, Yaseen M, Mehmood MU, Saeed A, Ahmad R (2024) Perceptions of small scale-farmers with regard to agricultural knowledge and information system: Case study of Punjab, Pakistan. *Sarhad Journal of Agriculture*, 40(4), 1102–1109. https://doi.org/10.17582/journal.sja/2024/40.4.1102.1109.

Martin GD, Coetze JA, Weyl SR, Parkinson MC, Hill MP (2018) Biological control of *Salvinia molesta* in South Africa revisited. *Biological Control*, 125, 74–80. https://doi.org/10.1016/j.biocontrol.2018.06.011.

Mas E, Lugo-Torres M (2013) *Common Weeds in Puerto Rico and US Virgin Islands Malezas Commons in Puerto Rico and Virgin Islands*. USDA Natural Resources Conservation Service Plant Materials Program.

Matouq M, El-Hasan T, Al Bilbisi H, Abdelhadi M, Hindiyeh M, Eslamian S, Duheisat S (2013) The climate change implication on Jordan: A case study using GIS and Artificial Neural Networks for weather forecasting. *Journal of Taibah University for Science*, 7(1), 44–55. https://doi.org/10.1016/j.jtusci.2013.04.001.

McDonald A, Riha S, DiTommaso A, DeGaetano A (2009) Climate change and the geography of weed damage: Analysis of U.S. maize systems suggest the potential for significant range transformation. *Agriculture, Ecosystems Environment*, 130(3-4), 131–140.

Mehari ZH (2015) The invasion of *Prosopis juliflora* and Afar pastoral livelihoods in the Middle Awash area of Ethiopia. *Ecological Processes*, 4, 13. https://doi.org/10.1186/s13717-015-0039-8.

Melander B, Holst N, Rasmussen IA, Hansen PK (2012) Direct control of perennial weeds between crops—implications for organic farming. *Crop Protection*, 40, 36–42. https://doi.org/10.1016/j.cropro.2012.04.029.

Milchunas DG, Lauenroth WK (1995) Inertia in plant community structure-state changes after cessation of nutrient-enrichment stress. *Ecological Applications*, 5(2), 452–458. https://doi.org/10.2307/1942035.

Ministry of Environment, Jordan (2009a) Jordan's Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC).

Ministry of Environment, Jordan (2009b) Overview of biodiversity status, trends and threats on biological diversity. In: The Fourth National Report on Implementation of the Convention on Biological Diversity. Jordan, Chapter 1.

Patterson DT (1995) Weeds in a changing climate. *Weed Science*, 43(4), 685–701. https://doi.org/10.1017/S0043174500081832.

Pichancourt JB, van Klinken RD (2012) Phenotypic plasticity influences the size, shape and dynamics of the geographic distribution of an invasive plant. *PLoS ONE*, 7(2), e32323. https://doi.org/10.1371/journal.pone.0032323.

Post GE, Densimore JE (1932) *Flora of Syria, Palestine and Sinai*. American University of Beirut, Lebanon.

Qasem JRS (2022) Parasitic Weeds of Jordan: Species, Hosts, Distribution, and Management – Part 2: Stem Parasites; Cuscutaceae, Loranthaceae Viscaceae. Bentham Science. https://doi.org/10.2174/9781681088778122020011.

Rajkumara S (2007) Crop weed interactions under environment stress - A review. *Agricultural Reviews*, 28(4), 283–288.

Rao AN, Johnson DE, Sivaprasad B, Ladha JK, Mortimer AM (2007) Weed management in direct-seeded rice. *Advances in Agronomy*, 93, 153–255. https://doi.org/10.1016/S0065-2113(06)93004-1.

Roger E, Duursma DE, Downey PO, Hughes RV, Steel L, Johnson SB, Leishman MR (2015) A tool to assess potential for alien plant establishment and expansion under climate change. *Journal of Environmental Management*, 159, 121–127. https://doi.org/10.1016/j.jenvman.2015.05.039.

Rogers HH, Runion GB, Prior SA, Price AJ, Torbert HA, Gjerstad DH (2007) Effects of elevated atmospheric CO2 on invasive plants: Comparison of purple and yellow nutsedge (*Cyperus rotundus* L. and *C. esculentus* L.). *Journal of Environmental Quality*, 37(2), 395–400. https://doi.org/10.2134/jeq2007.0155.

Rubiales D, Pérez-de-Luque A, Fernández-Aparico M, Sillero J, Román B, Kharrat M, Khalil S, Joel D, Riches C (2006) Screening techniques and sources of resistance against parasitic weeds in grain legumes. *Euphytica*, 147(1-2), 187–199. https://doi.org/10.1007/s10681-006-7399-1.

Shad RA (2015) Weeds and weed control. In: Nazir S, Bashir E, Bantel R (Eds) *Crop Production*. National Book Foundation, Islamabad, Pakistan, 175–204.

Shahidul HM, Eom MY, Uddin MR, Park TS, Kang HW, Kim DS, Park KW (2014) Weed population dynamics under climatic change. *Weed Turfgrass Science*, 3(3), 174–182. https://doi.org/10.5660/WTS.2014.3.3.174.

Smith R (2012) Mechanical weed control tools for vegetables. *Weed Research and Information Center UCCE Monterey County*, Salinas Valley.

Smith RG, Ryan MR, Menalled FD (2011) Direct and indirect impact of weed management practices on soil quality. In: Hatfield JL, Sauer TJ (Eds.) *Soil Management: Building a Stable Base for Agriculture*. Soil Science Society of America, Madison, W. I., USA, 275–286.

Solaimalai A, Ramesh RT, Baskar M (2004) Pesticides and environment. In: Kumar A (Ed) *Environmental Contamination and Bio-reclamation*. APH Publishing Corporation, New Delhi, India, 351–394.

Stapleton JJ, DeVay JE (1995) Soil solarization: A natural mechanism of integrated pest management. In: Reuveni R (Ed) *Novel Approaches to Integrated Pest Management*. Lewis Publishers, Boca Raton, 309–322.

Sultan SE (2000) Phenotypic plasticity for plant development, function and life history. *Trends in Plant Science*, 5(12), 537–542. https://doi.org/10.1016/S1360-1385(00)01797-0.

Taifour H, Dexter KG, Al-Bakri J, Miller A, Neale S (2022) A state-of-the-art vegetation map for Jordan: A new tool for conservation in a biodiverse country. *Conservation*, 2(1), 174–194. https://doi.org/10.3390/conservation2010012.

Tremmel DC, Patterson DT (1993) Responses of soybean and five weeds to CO2 enrichment under two temperature regimes. *Canadian Journal of Plant Science*, 73(4), 1249–1260. https://doi.org/10.4141/cjps93-164.

USA U-A (2008) Germplasm Resources Information Network (GRIN) [Online Database]. National Germplasm Resources Laboratory, Beltsville, USA.

USDA-NRCS (2008) The Plants Database. National Plant Data Center, Baton Rouge, USA.

Wan JZ, Wang CJ, Yu FH (2017) Modelling impacts of human footprint and soil variability on the potential distribution of invasive plant species in different biomes. *Acta Oecologica*, 85, 141–149. https://doi.org/10.1016/j.actao.2017.10.008.

Weaver SE, McWilliams EL (1980) The biology of Canadian weeds. 44. *Amaranthus retroflexus* L., *A. powellii* S. Wats. and *A. hybridus* L. *Canadian Journal of Plant Science*, 60(4), 1215–1234. https://doi.org/10.4141/cjps80-175.

Weber E (2003) *Invasive Plant Species of the World: A Reference Guide to Environmental Weeds*. CAB International, Wallingford, UK.

Zhang W, Parker KM, Luo Y, Wan S, Wallace LL, Hu S (2005) Soil microbial responses to experimental warming and clipping in a tallgrass prairie. *Global Change Biology*, 11(2), 266–277. https://doi.org/10.1111/j.1365-2486.2005.00902.x.

Zimdahl RL (2007) *Fundamentals of Weed Science*. Elsevier/Academic Press, Amsterdam, Boston.

Ziska LH (2001) Changes in competitive ability between a C4 crop and a C3 weed with elevated carbon dioxide. *Weed Science*, 49(5), 622–627.

Ziska LH, George K (2004) Rising carbon dioxide and invasive, noxious plants: potential threats and consequences. *World Resource Review*, 16(4), 427–447.