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Field Bindweed Biology and Growth Resumption

Abdessatar Omezine[1*] • Fethia Harzallah-Skhiri[2]

[1] Department of Plant protection and Biological Sciences, Weed Science Laboratory, High Institute of Agronomy Chott-Mariem (4042) Sousse, Tunisia
[2] Agrobiodiversity Unit, Higher Institute of Agronomy Chott-Mariem (4042) Sousse, Tunisia, /Higher Institute of Biotechnology of Monastir, Tunisia

Corresponding author: * **abdessatar.omezine@yahoo.fr**

ABSTRACT

Glasshouse and growth chamber experiments were conducted at the farm of the High Institute of Agronomy in Chott-Mariem to investigate the sprouting potential and emergence of *Convolvulus arvensis* rootstock from 2006 to 2007. The effects of burial depth, desiccation, length of rootstock, and soil moisture on sprouting, the value of sprouting and the test of viability of *C. arvensis* rootstock were investigated in a glasshouse. The vertical distribution of rootstock of *C. arvensis* was estimated *in situ*. The creeping underground system can reach 70 cm depth depending on the soil type. The upper horizon holds the majority of this underground system; viability decreases with the highest viability for the underground structure located at a depth between 10 and 20 cm. The plant was able to regenerate either by roots or rhizomes; however, shoots from rhizomes were more vigorous than those from roots when these structures were isolated. Planting depth decreased the emergence of rhizome fragments. At the same depth of planting, the long rhizome fragments emerged more rapidly than short rhizome fragment since the former contain more food reserves; therefore, the smaller fragments sprouted but were not able to emerge. The length of the *C. arvensis* rootstock fragment is critical for sprouting. The rhizomes of *C. arvensis* exposed to ambient temperature rapidly lost water content which is essential for survival. Irrigation regimes and soil type influenced growth and sprouting. These findings in integrated *C. arvensis* management could reduce infestation by preventing emergence and sprouting from small rhizome fragments in the population.

Keywords: *Convolvulus arvensis* L., depth, emergence, rhizome, sprouting

INTRODUCTION

Convolvulus arvensis originated in Eurasia but has spread across the world to become a cosmopolitan species growing between 60°N and 45°S latitudes (Weaver and Riley 1982). A native of Mediterranean Europe, *C. arvensis* has been introduced throughout most temperate and dry subtropical climates, including Northern Africa, Australia, Eurasia, India, New Zealand, Hawaii, Chile, and North America (Aneja and Srinivas 1990; Wagner *et al*. 1990; Chapman 1991; Gleason and Cronquist 1991). *C. arvensis* is one of the 10 noxious weeds in the world and 54 countries reported that it is found as a weed in 32 crops (Holm *et al*. 1977).

C. arvensis is considered an important weed in cultivated fields and vineyards. It is a common weed in gardens, fields and on road-sides (Labbé 1950; Omezine 1990). It produces few seeds when growing in competition with crops. Seeds serve as means of propagation and spread into new areas. However, the rapid increase in plant numbers after initial establishment is mainly attributable to the regenerative capability of rootstocks (propagule production) due to numerous adventitious buds. *C. arvensis* is difficult to control because it can propagate from a deep and extensive root system and reproduces primarily vegetatively from underground rootstocks. In addition, adventitious shoots arising from a network of rootstocks reduce crop yields and interfere with harvest (Liebman *et al*. 2001). *C. arvensis* can spread by seed, root fragments, farm implements, infested soil adhering to the roots of nursery stock, root growth from infested areas, and by animals (Lyons 1998). Despite being initially dispersed by seeds to new sites, it also can reproduce successfully and vigorously by underground rhizomes (Weaver and Riley 1982; Mitich 1991). Deep-set rhizomes also may persist for several years as a function of the efficient use of carbohydrate reserves (Bailey and Davison 1984). Fragmentation of rhizomes is one of the primary mechanisms by which it disperses and persists in cultivated fields (Buhler *et al*. 1994). Re-establishment by means of root or rhizome fragments, however, may be reduced by techniques that either minimize tilling or expose such fragments to desiccation and sun (Sherwood 1995).

Competitive ability of *C. arvensis* is due largely to its extensive root system. Vegetative underground parts have a large amount of food reserves compared to seeds; therefore shoots sprouted from adventitious buds have more considerable competitive ability than plants developed from seeds (Kazinczi *et al*. 2006). Competition for nitrogen is especially strong. *C. arvensis* can cause problems (Hunyadi *et al*. 2000); *C. arvensis* reduced NPK content of oilseed rape shoots as compared with the weed free control pots (Kazinczi *et al.* 2007). Losses in crop production can be 100% in dry years and in small grains a 20% average loss is expected when *C. arvensis* is present. *C. arvensis* competition for nutrients and water may reduce productivity of native plants; although this has only been studied in crop plants where yield reductions range from 0 to 100% (Swan 1980). Competition from field bindweed for soil moisture may have greater impact in dry years. Low light conditions induce dormancy in *C. arvensis*. Although *C. arvensis* is a poor competitor under conditions of low light intensity and low water stress, its deep rhizomes provide an important dormancy mechanism for survival (Dall'Armelliana and Zimdahl 1988, 1989).

C. arvensis root systems apparently do not utilize the same soil-water and nutrient resources as those of most cultivated crops do. Several studies showed that *C. arvensis* does not apparently compete for water with most irrigated crops, primarily because root penetration and depth does not overlap between *C. arvensis* and preferred crops (Blank 1987; Black *et al*. 1994). However, under water stress, *C. arvensis* can be a better competitor than most cultivated crops (Stahler 1948). *C. arvensis* will shade seedling plants

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as it twines around standing vegetation, and in small grain crops will cause the plants to lodge (lay on the ground) making harvest difficult. Moreover *C. arvensis* is a toxic plant and will cause cattle, sheep, and goats to become ill when the diet contains more than 5% (Todd *et al*. 1995; Loss and Prather 2007).

Many strategies to control this species have been used but the plant persists. Choosing an appropriate method and timing control requires an extensive understanding of the biological behavior of *C. arvensis*. The effects of factors such as temperature, burial depth, and size of the root segment on regenerative capacity of *C. arvensis* are not known. The objectives of this research are (1) to determine the sprouting potential of rootstock, (2) to study the effect of temperature, burial depth, and length of rootstock on sprouting, (3) to determine the effect of shoot removal on resprouting ability of rootstock.

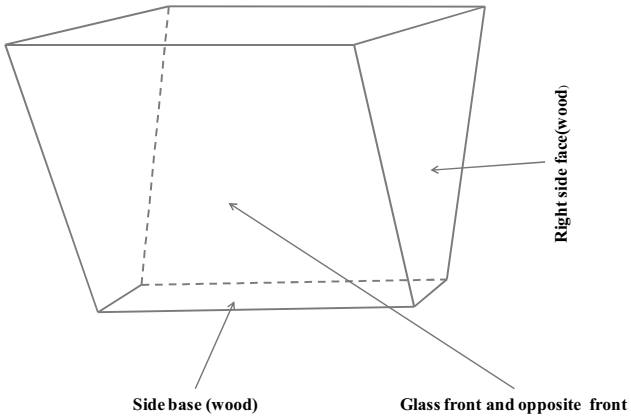

Fig. 1 View of glass-faced container.

MATERIALS AND METHODS

Experimental sites and plants

C. arvensis rootstocks were collected from the farm of the High Institute of Agronomy, Chott-Mariem (41° 92′ N; 9° 80′ E). The soil used in the study was a mixture of 1/3 vermiculite, 1/3 peat moss and 1/3 sandy soil. Plastic pots (16 cm diameter, 30 cm depth) or plastic trays (50 cm length, 26 cm width, and 15 cm depth) were used. Studies were conducted in a greenhouse where they were subjected to environmental fluctuations. The plants were watered as needed to maintain adequate soil moisture.

Rhizomes and roots samples were collected from a solitary stand of *C. arvensis* at the farm of the High Institute of Agronomy (ISA) for use in vegetative propagule studies. These undamaged propagules of similar thickness were used in experiments to examine the viable, propagule length and the effects of environmental factors on sprouting and growth. All rhizomes used in these experiments had at least one node. After harvest, above- and below-ground plant parts were washed, weighed and dried in air ambient and reweighed.

Spatial distribution production and viability of *C. arvensis* underground system

To obtain rough information about spatial distribution of the underground system in the soil horizons, small soil monoliths were taken on May 2007 according to Görbing (1948), each of which was 400 cm^2 in area. Layers of soil were taken at the following depths: 0-2, 2-12, 12-22, 22-2, and 32-42 cm (Köpke 1979). Soil was washed through a screen and rhizome fragments were isolated. Before extracting the monoliths, the vegetative above-ground part was cut to determine biomass production. The rhizome fragments were replanted at 2 cm depth, in containers filled with soil which was a mixture of 1/3 vermiculite, 1/3 peat moss and 1/3 sandy soil to test the sprouting. Rhizome sprouted is viable.

Observation of underground system growth pattern and development of *C. arvensis*

An experiment was designed on March 2007 to make phenological observation of the underground system, growth pattern and development of *C. arvensis*. This experiment utilized glass-faced containers (**Fig. 1**), generally inclined at angles of about 25°C from the vertical (glass side down). The glass-faced containers are made of wood with two side's walls containing a removable glass plate. A thick paper is used to cover the glass and protect the underground system from light. The size of the glass observation containers is at the bottom 10 cm large and 50 cm long, at the upper surface 15 cm large, and the containers are 40 cm high.

Effect of planting depth

To study the effect of planting depth on sprout emergence, 5-cm long rootstocks of *C. arvensis* were planted horizontally at 0, 2, 5, 10, 20, 30 and 40 cm deep in tubes filled with soil which was a mixture of 1/3 vermiculite, 1/3 peat moss and 1/3 sandy soil. The collected rhizomes were buried at indicated soil depths. Pots were kept in a greenhouse at 25 ± 2°C with natural light. There were ten 8-cm long rootstocks per treatment. Rhizomes were placed at the nominated depth in each tube. The tubes were filled with standard potting soil mix to 3 cm below the rim. The tubes were then sunk into the hall with rims protruding 5 cm above the ground level. These tubes had no soil disturbance throughout the experiment. The containers were inspected weekly to record emergence time of each plant. After the growth period, all plants were harvested simultaneously. Below-ground regenerative organs and aerial shoots from each plant were weighed separately. Fine roots were excluded. The pots were watered every two days and placed in a greenhouse. The experimental design was completely randomized with five replicates.

Effect of rootstock length on sprouting

To study the effect of rootstock length on sprouting, 1-, 3-, 6-, 9- and 12-cm-long rootstocks of *C. arvensis* were planted horizontally, 3 cm deep in plastic trays filled with peat moss. Trays were kept in a greenhouse at 25° ± 2°C and irrigated every two days with 500 ml of water. There were ten 5-cm-long rootstocks per treatment. After 8 weeks, sprouts were counted and sprouted rootstocks were expressed as a percent of the total number of planted rootstocks.

Effect of desiccation

Fresh rhizomes were desiccated for varying periods of time in laboratory air temperature (mean temperature 28°C and mean relative humidity 60%). In mid-March, rhizomes were collected from outdoor containers, cut into 5-cm pieces, weighed and put on a laboratory table. Every two days, five rhizomes were taken, reweighed and planted at a 3 cm depth; each one a 1-liter pot filled with standard potting soil mix, watered and kept in the greenhouse for about two weeks. The rhizomes that emerged were counted.

Soil type and moisture

This experiment was conducted as a 2-way factorial design with five replicates. The factors were soil type, and soil moisture. Rhizomes were planted at a 3 cm depth in clayey, sandy, loamy-sandy soil in 8 cm diameter pots in March 2007. A third of the pots were watered daily; the second third were watered weekly with 100 ml of water, while the last third were not watered at all. The pots were placed in a greenhouse without a cooling system, but the atmosphere was maintained at 25°C with automatic ventilation. The time of sprouting was recorded for each rhizome and the rhizomes that sprouted were counted.

Value of sprouting

Fresh rhizomes collected from outdoor containers were cut into pieces 5-cm in length without apical meristems, weighed and very gently pressed into standard potting soil mix of pots that had been

well watered about 2 hours earlier. The pots were kept in a greenhouse until the apical meristem emerges. After sprouting, all pieces were reweighed and the difference between the initial and the final weight indicated the value of sprouting.

Statistical analysis

Treatments were arranged in a completely randomized design with 10 replications. Data were subjected to ANOVA and the means were separated using the F-test at P = 0.05 (Little and Hill 1977) and standard errors were used to compare treatment means.

RESULTS

Spatial distribution, production and viability of *C. arvensis* underground system

The excavation study indicates that the underground system could reach 70 cm deep and more than 60% of this underground system was located in the upper 30 cm of soil layer and most rhizomes are produced in this layer of soil (**Fig. 2**). The weight of the biomass of the aboveground part converted to weight/ha, was 15 tons but the biomass of underground stems and fleshy roots was 7 tons; however, the mean number of seeds produced per plant was 500.

The viability of the underground stems and fleshy roots varied with depth. This viability decreased with the excavated depth (**Fig. 3**). However, those located in the lower 30 cm of the soil layer showed the least viability, i.e. 30%; under this layer the viability was nil. In addition, the viability of propagules located in the upper 5 cm of soil layer was also low (42%). Probably, these low viabilities of the propagules placed in the uppermost and the lowest horizons were due to their age. The propagules located in the uppermost or in the deepest soil layers were respectively either very young or exhausted carbohydrate reserves from repeated sprouting to support resumption. Moreover, the viability of rhizomes was better than the viability of root fragments.

Observation of underground system growth pattern and development of *C. arvensis*

In this study a description of spatial distribution in some detail of the underground *C. arvensis* grown from rhizome fragments in view glass faced boxes is summarized. It was found that the planted rhizome fragments formed new aerial shoots. From the underground part of this shoot, initiation of root emergence started in many directions: (1) vertical roots, (2) lateral roots, and (3) secondary vertical roots. The vertical roots grew directly down and the lateral roots grew out horizontally before turning down to form secondary vertical roots. These gave rise to more laterals that again turned down to form verticals and so on. At the point where laterals turned down, rhizomes developed from adventitious root buds and grew upwards to emerge as new shoots. Less commonly, shoots formed along the horizontal portion of lateral roots. Apart from the initial aerial shoot, all other shoots originated from root-borne stem buds which gave rise to vertical underground stems or rhizomes. At nodes along the rhizomes were buds that can develop into branch rhizomes.

Effect of planting depth

There is an inverse relationship between the depth of burial and the emergence of field bindweed rhizomes, as shown in **Fig. 4**. For rhizomes, emergence dropped off rather sharply with increase in depth. Planting depth also influences the rate of emergence. At 2 cm depth, rhizomes emerged 5 days after plantation; at 5 cm, rhizomes emerged 12 days after plantation; at 10 cm, rhizomes emerged 19 days after plantation, at 20 cm, rhizomes emerged 24 days after plantation and at 30 cm, rhizomes emerged 30 days after plantation, at 40 cm, no emergence of rhizomes. Consequently, the initial areal shoot growth decreased with the depth.

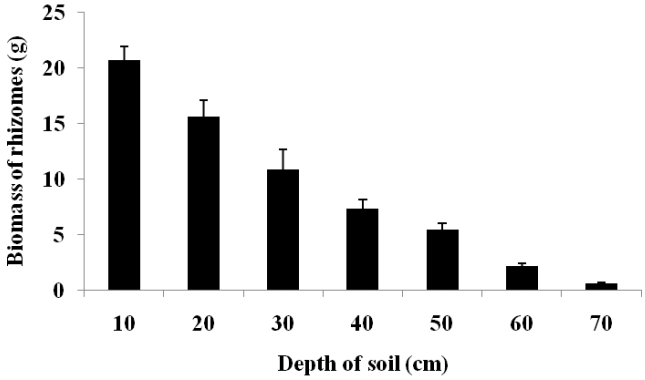

Fig. 2 Biomasses of underground part of *C. arvensis* excavated from soil layers (weight in g per layer). Values represent means ± Standard Error (SE).

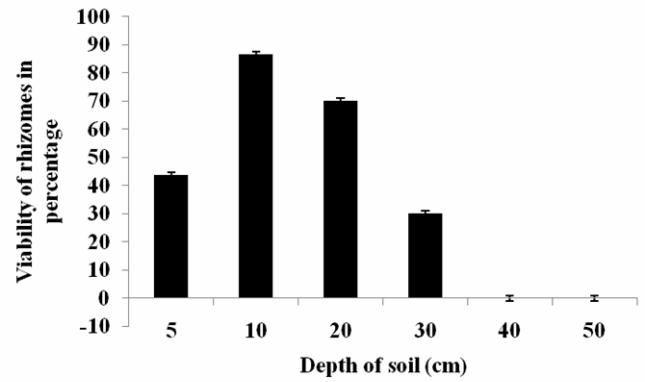

Fig. 3 Viability test of underground stem of *C. arvensis* excavated from soil layers (in percentage). Values represent means ± Standard Error (SE).

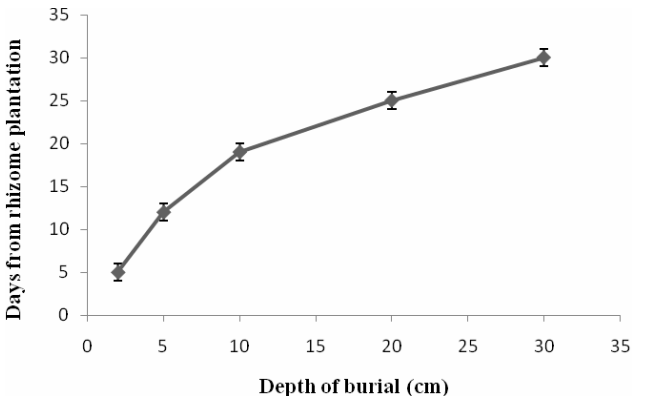

Fig. 4 Effect of depth of burial on sprouting of *C. arvensis* rhizomes. Values represent means ± Standart Error (SE).

Effects of propagule length

The results showed that the length of *C. arvensis* rhizomes influenced the sprouting and survival (**Table 1**). With 1 cm-rhizome length, the sprouting was nil. For 3 cm length, the percentage of rhizomes that sprouted into shoots was 60%; but the survival percentage of sprouted rhizomes dropped to 15%. However, the percentage of survival for 12 cm- rhizomes that all had sprouted, dropped to 55%. A positive relationship has been established between propagule length and sprouting. Therefore, the growth was more influenced than the sprouting of rhizomes. Generally, the percentage of rhizomes that had successfully grown in shoots was less than the percentage of rhizome that one's sprouted. The rhizomes that were sprouted were decayed or dead.

Table 1 Effect of rhizome length on sprouting, death, decaying and growth (number of rhizome surviving fragments/20 rhizome fragments).

Length	Rhizomes			Growth of rhizomes
(cm)	Sprouted	Decayed	Death	
1	0	20	0	0
3	12	8	9	3
6	14	5	9	5
9	15	6	9	6
12	20	0	9	11

Table 2 Rhizome sprouting in relation with irrigation regime (based on 20 rhizomes planted).

	Rhizomes sprouted	Shoot number/rhizome
With irrigation	1 shoot	0
Irrigation every day	8 rhizomes	3
Irrigation every week	15 rhizomes	16

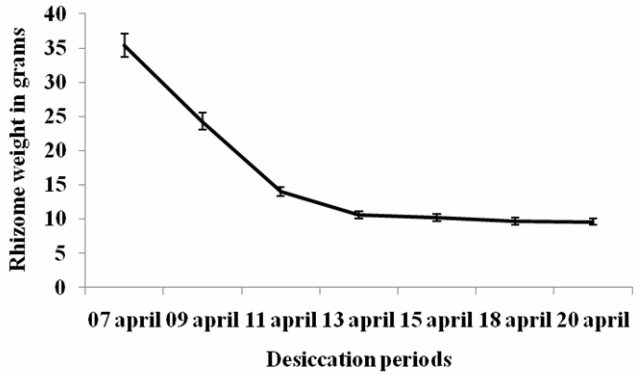

Fig. 5 Effect of drying periods on sprouting of *C. arvensis* rhizomes. Values represent means ± Standard Error (SE).

Effect of desiccation

This experiment showed rhizomes to be sensitive to desiccation. With *C. arvensis* rhizomes, drying less than 40% of the original moisture content was lethal. As we can see, the water loss was greater and faster at the beginning of the experiment than the last one (**Fig. 5**). This is proved that the rhizomes did not have any protective zone from desiccation.

Soil type and irrigation regimes

Growth and sprouting of *C. arvensis* rhizomes depends on the irrigation regimes. The soil type influenced the sprouting of rhizomes but the difference was not significant at least in this study. The results indicated that this species preferred heavy soils where it grows more. With infrequent irrigation, the sprouting of the rhizomes was reduced. Well-watered rhizomes sprouted well (**Table 2**).

Value of sprouting

In this work, rhizome fragments of *C. arvensis* were weighed before and after sprouting. The difference between them indicated the quantity of food reserves utilized to sprout is termed the value of sprouting. This value was estimated to be 29.6%. These data indicates that the food reserves had an important role in the regenerative capacity.

DISCUSSION

Vertical distribution of rootstock on *C. arvensis*

C. arvensis has an extensive underground root/stem system. *C. arvensis* has deep roots that store carbohydrates and proteins. They help *C. arvensis* spread vegetatively and allow it to resprout repeatedly following removal of above-ground growth. It has a massive rootstock system (80% of total plant biomass) that provides it with a large pool of stored carbohydrates for regrowth, and numerous belowground buds that can develop into new shoots. Most roots perish at the end of the season, but some persist through the winter. 60% of the total *C. arvensis* rootstock biomass is generally within the top 30 cm of soil, but few roots grow below 60 cm. In localities where there is a high water table, the tap root may branch at a depth of 0.6 m or less, while in other localities, it may penetrate to a depth of 3 m or more before branching profusely. A deep and extensive root system with reserves that allow bud regeneration from the roots makes *C. arvensis* difficult to kill.

Growth resumption

Vigorous vegetative reproduction is of prime importance in the survival and spread of *C. arvensis.* It is capable of vegetative reproduction by sprouting from adventitious buds on vertical and lateral roots; sprouting from root fragments; and forming new shoots from adventitious buds following removal of top-growth and/or the root crown. *C. arvensis* shoots can be produced every year from adventitious buds on the creeping root system, but density of shoots varies by year. *C. arvensis* produced predominately single sprouts at any point on the rootstock and the new sprouting occurred at both the old and new locations on the rootstock. Visual observation of sprouting showed that sprouts were produced mostly at the end of rootstock in *C. arvensis.* Roots form at the distal end and buds form at the proximal end. This indicates that an acropetal movement of auxin from the proximal to the distal end of *C. arvensis* root fragment might underlie polar root formation (Abbas *et al.* 1995).

There was a well-developed main sprout on the rootstock with several secondary sprouts with a lesser degree of development. These data suggest that shoot dominance might be present in *C. arvensis*. The roots and rhizomes become winter hardy in autumn and can withstand low temperatures. Rhizomes and attached lateral roots can persist independently if severed from the primary root (Weaver and Riley 1982). The above ground parts of the plant are susceptible to winter temperatures; however, the deep taproot escapes these killing temperatures and will re-grow new plants once temperatures reach 15°C. Water stress and low light conditions cause the roots to become dormant and once dormant, the roots survive low temperatures. During periods when dormant the starchy taproot and lateral roots provide nutrients for the plant. Low temperatures kill shoots.

Survival and longevity of *C. arvensis*

Various mechanical control methods have been employed to control *C. arvensis* in agricultural settings. Tillage systems have generally provided negative results for *C. arvensis* control. *C. arvensis* responds to plowing, disking, and rod weeding by increasing bud formation just below the tillage layer. New shoots rapidly emerge and carbohydrate reserves are replenished in a few weeks. Tillage is clearly effective on seedlings. However, plants may form perennial buds within six weeks of emergence. Tillage used for seedling control should be conducted within the first few weeks to prevent plants from surviving. Infrequent tillage used in fields may actually promote *C. arvensis* infestations by eliminating annual weed competition and spreading root fragments around. If *C. arvensis* patches are evident, avoid tilling them to prevent spread of the rootstocks. In this case, spot treatment herbicide applications will be more effective. Intensive cultivation was historically used for field *C. arvensis* control. This entailed cultivating at least every two weeks to exhaust carbohydrate supplies in the roots. This type of tillage strategy is not recommended, due to the increased potential for erosion and soil moisture loss. Other intensive mechanical strategies include hand pulling or grubbing. These must be done repeatedly to be effective.

Tillage is the major mechanism by which rootstock is cut and spread around a field. Tillage operations that produce short rootstock segments would be more effective in

reducing *C arvensis* densities. However, tillage operations produce many long fragments which could reproduce and survive. Numbers of rootstock fragment with emerged sprouts were the highest in 12-cm planting depth of *C. arvensis*. Whereas rootstock fragments of 1 cm length did not sprout. In other research, the maximum depth of emergence of sprouts was 90 cm for *Cirsium arvense* (L.) Scop (Donald 1994). In our study, visual observation revealed that although rootstocks produced sprouts, they failed to emerge because of lack of adequate growth. These observations imply that the rootstocks may not have enough accumulated reserves to sustain shoot growth and to develop a profuse root system needed to allow sprouts to grow up to the surface of the soil. Sprout emergence was not synchronous for all planting depths especially because emergence was delayed with increased planting depths (data not shown). In other species such as *Helianthus tuberosus* L., shoot emergence was remarkably synchronous for each planting depth up to 30 cm deep (Swanton and Cavers 1988). One reason might be the higher amounts of accumulated reserves resulting in higher mass per unit length of rootstock in *Helianthus tuberosus* than *C. arvensis*. Incorporation of rootstock segments deeper into soil by appropriate tillage would be an effective means of control particularly for *C. arvensis*. Deep burial has been suggested as an effective means of control in several perennial species such as *Cynodon dactylon* (Satorre *et al*. 1996), *Cyperus rotundus* (Santos *et al*. 1997), and *Cirsium arvense* (Donald 1994).

Usually, tillage results in redistribution of rootstock segments in the soil profile. Rootstocks left on the surface of soil are more prone to be killed during either winter or summer and those buried in the soil are more likely to survive winter or summer conditions. *C. arvensis* exposed to air temperature ambient lost more than 40% of water content which was lethal. However, the burial of *C. arvensis* rootstock fragments into the soil profile increased the survival. In *Sorghum halepense* depth of burial greater than 40 cm was clearly related to total rhizome survival during the overwinter exposure (Warwick *et al.* 1986).

Management of *C. arvensis*

C. arvensis requires active management once it is established because of its potential to regenerate rapidly. Even small infestations should be viewed as serious threat and managed aggressively. It is also tolerant of a variety of environmental conditions which makes it highly competitive for resources (Rutledge and McLendon 1998). Due to the vegetative reproductive ability of *C. arvensis* as well as the large seed bank of established populations, successful control requires repeated applications over several years. A deep and extensive root system with reserves that allow bud regeneration from the roots makes *C. arvensis* difficult to kill and most chemical herbicide treatments require 3 to 5 years to kill mature field bindweed plants. The difficulty and expense of control of *C. arvensis* by cultivation, competitive crops, and herbicides warrants emphasis on biological control efforts. Previous studies of biological control agents of *C. arvensis* have used insects. Many of these insect biocontrol agents have been disappointing because of lack of specificity (Rosenthal and Buckingham 1982) or incomplete control (Wang and Kok 1985). Biological control with fungal pathogens of the genus *Septoria* and of the genus *Phoma* has been investigated. The species demonstrate sufficient pathogenicity and host specificity to be regarded as promising biocontrol agents (Giannopolitis and Chrysayi 1992). The host-specific fungus, *Erysiphe convolvuli*, has also been evaluated as a potential biocontrol agent of field bindweed (Abu-Irmaileh and Al-Raddad 1999). An inoculum of the fungus *Phomopsis convolvulus* has caused severe damage to field bindweed plants at all growth stages (El-Sayed *et al*. 2001). Biological control of invasive species has a long history, and there are many important considerations to be made before the implementation of a biological control program. There are currently no registered biological control agents for *C. arvensis* in Tunisia.

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