Cultivation of *Carnegiea gigantea* from Seeds: a Journey in Desert Ecology

Enrico Ceotto
CRA-CIN Research Center for Industrial Crops
Via di Corticella, 133
40128 Bologna, Italy
enrico.ceotto@entecra.it

Introduction

The saguaro (*Carnegiea gigantea* [Engelm.] Britton and Rose) is a tall, columnar cactus that occurs in much of the Sonoran Desert, extending throughout southern Arizona, USA, and Western Sonora, Mexico. The white blossom of the saguaro is the state flower of Arizona. The saguaro has been used by Pima and Tohono O'odham Indians, primarily for the edible fruits, but also for building materials and tool production. Moreover, archeological evidence indicates that the Hohokam used saguaro wine for etching objects over 1,000 years ago. The saguaro has been largely used by the entertainment industry as a landscape emblem for western films and cartoons (Nobel, 1988).

In 1933, to protect the forest of giant, multi-branched saguaros that was present at the base of the Rincon Mountains, President Herbert Hoover proclaimed the Saguaro National Monument near Tucson, Arizona (now a National Park). Unfortunately, this saguaro population experienced a progressive decline over the following 50 years. This has stimulated many research and monitoring activities that attempt to understand the reasons for the dramatic decline. As a consequence of the studies devoted to saguaro environmental biology, this species has become one of the most intensively studied, non-agricultural plants of the world (McAulife, 1993). Despite the abundance of literature regarding the ecology of saguaro, little was reported about saguaro cultivation. The scope of this article is to disseminate methods and secrets, for successful saguaro cultivation from seeds, learned from 20 years of experience. Cultivating saguaros throughout their juvenile stage is an intriguing activity, because juvenile plants make excellent home, garden, and office plants for many years, even in climates unfavourable for the species. In addition, it also provides the opportunity to discover some inner secrets of desert ecology. This discussion is limited to the phases of cultivation starting from seed germination until the juvenile stage of 40-50 cm, a period during which the plant can be cultivated in pots. According to Steenbergh and Lowe (1976) *seedlings* refers to plants less than one year old, *juveniles* are plants over 1 year old that have not reached flowering size, and *adults* are flowering plants, generally over 2 m in height.

Outline of saguaro ecology

The key strategies of saguaro adaptation to arid environments can be summarized as follows:

i) the saguaro, like other cacti, keeps its stomata open primarily during the night, when water losses are negligible, and assimilates carbon dioxide (CO_2) which is temporarily converted into malic acid. During the daytime, the saguaro tends to close its stomata, and to use the CO_2 that is progressively released within the plant to produce sugars. This photosynthetic pathway is termed Crassulacean Acid Metabolism or CAM and results in very little water consumption (Nobel, 1988);

ii) this species has a potential life-span of about three centuries and an average life-span of 150–175 years (Pierson and Turner, 1998);

iii) flowering, the reproductive stage, begins when the plant is about 2.1 m tall and fifty years old (Steenbergh and Lowe, 1969). Each adult produces thousands of tiny seeds annually for many decades (Steenbergh and Lowe, 1977). The number of branches is influenced by the severity of drought conditions; vigorous individuals normally develop 10-20 branches where annual rainfall is relatively abundant, whilst in the driest locations the plants may never develop branches. The ecological function of branches is to increase the number of flowers, and therefore of seeds produced by the plant (Bowers, 2003);

iv) saguaro cohorts establish periodically (i.e. 10-30 % of the years) when a favorable combination of climatic and microhabitat conditions are met. The microhabitat conditions necessary for saguaro establishment predominantly occur beneath a canopy of shrubs or small trees, the so-called "nurse plants". Plants of different sizes and shapes can nurse saguaro; the leguminous tree *Cercidium microphyllum*; the dense, small shrub *Ambrosia deltoidea*, and the open canopied shrub *Larrea tridentata* (Drezner, 2006). Basically, nurse plants protect the juvenile saguaros against excessive evaporation, extreme heat and cold, animal predation and mechanical injury (Steenbergh and Lowe, 1977). Favourable microhabitat conditions may occur among rocks which typically concentrate and prolong availability of soil moisture. Moreover, during cold winter nights, nocturnal re-radiation from sun exposed rocks moderates the intensity and duration of low temperatures. (Steenbergh and Lowe, 1977);

v) in the long term, the recurrent occurrence of fatal freezing events, leads to substantial fluctuation of saguaro populations in number, size and age (Steenbergh and Lowe, 1977).

The seeds

The adult saguaro annually produces many tiny black seeds of approximately 1.5 mm length (Fig. 1). Using a precision balance, I estimated an average weight of 1.54 mg (i.e. 1.087 g = 705 seeds). It seems incredible that such an

enormous plant grows from such a small seed. The saguaro begins its reproductive stage at age 50 -75 years and lives on average 150 -175 years. Each saguaro fruit contains about 2000 -2005 seeds. With an average production of 200 fruits per year, a healthy saguaro can produce about 40 million viable seeds during its 100-year reproductive life span. In order to assure the maintenance of a saguaro population, at least one of these seeds must germinate and survive, during that period, until the age at which it becomes a reproducing member of the population (Steenbergh and Lowe, 1977). The survival strategy for saguaro populations is therefore clear: producing a huge amount of tiny seeds in order to assure that at least a few of them can survive. In harsh arid environments, producing fewer larger seeds, is not a good strategy since in some years, no seeds may survive.

Figure 1. Saguaro seeds (EC)

Germination requirements

The germination of viable saguaro seeds requires that a set of conditions be met:

i) well drained soil
ii) prolonged exposure to moisture
iii) presence of light
iv) proper temperature

The choice of a well-drained substrate is crucial for seed germination and seedling establishment, which is indeed the most critical period in the life of the species. The saguaro cannot establish on soils containing relatively high fractions of clay and silt (Steenbergh and Lowe, 1977). Saturated soils high in clay and silt have low oxygen content. This facilitates attacks by fungi and bacteria on the soft tissue of the saguaro seedlings, resulting in death. To avoid this, use peat as a substrate for germination and seedling establishment. Peat is a superior substrate owing to its substantial water storage coupled with remarkable air content. Peat is easily available commercially and inexpensive; it is also available in compressed diskettes expandable by watering.

Sandy soils can be used as well, since they are characterized by excellent water drainage and air circulation. However seedlings in sand require more frequent watering. A cautionary remark, several soils appear to be sandy when dry, but indeed contain a relevant fraction of silt, thus are unsuited for saguaro seed germination and establishment. As a rule of thumb, if the soil becomes sticky when soaked, it shouldn't be used as a germination substrate. Be aware that the "pure sand", commonly sold as a building material, is a poor substrate because it contains too few nutrients. It appears that germination occurs faster in peat than in sandy soils. One possible explanation is that humic acids, abundant in peat, may act as a detergent for substances that inhibit seed germination; one alternative explanation lies on the better water availability assured by peat.

The so-called "cactus soils" available commercially are a mixture of peat and volcanic sands, hence a good compromise, albeit they usually cost much more than peat. Conversely, potting soils for flowers and garden plants shouldn't be used, because they often contain a portion of added clay.

Pots of different sizes and shapes can be used, providing they have a drainage hole. Flat and shallow pots are preferable, however, because they can host many seedlings. Pots for bonsai are well suited although relatively expensive.

It is important to emphasize that germination, and the first year of seedling cultivation should be carried out indoors. Prolonged exposure to moisture after sowing (i.e. misting conditions) are imperative for both seed germination and survival. Misting can be assured by covering the pot with a transparent plastic cover. A plastic cover is more practical than a plastic bag because it allows for easier inspection of the pots and also provides more aeration. Usually, germination takes place in 10 to 14 days at 20 °C and in just 3 to 5 days at 30 °C. The ideal period for sowing is from March until September. During fall and winter periods the growth of seedlings is normally stunted due to lack of sunlight.

Gravel and small rocks on soil surfaces are decorative and appealing and utilized to slow water evaporation from the soil surface. While this is an advantage in sandy soils with little water storage (Fig. 2), it can be a problem in peat, a substrate with substantial water storage.

Sowing operations

It is convenient to soak the soil before sowing. I suggest using a pencil, or other sharply pointed tool, for making holes in the soil for each individual seed. The seeds should be buried at a depth not exceeding their length (i.e. about 1-2 mm depth). Well aerated soils permit some light to reach the seeds, providing they are not buried too deeply. In order to avoid crowding, it is wise to leave a distance of about 2 cm between each hole. Put one seed in each hole, then, gently cover the seeds. Although time consuming, this

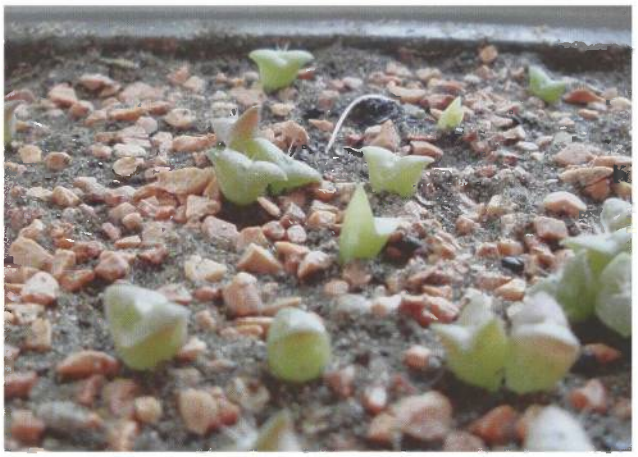

Figure 2. Small rocks on the surface among saguaro seedlings can improve water storage of sandy soils by preventing water evaporation (EC).

method of planting results in high rates of seed germination and survival, with little or no competition between the seedlings. Attempts to distribute the tiny seeds evenly on the soil surface and cover them with a supposedly uniform thin layer of soil, leads to lack of uniformity in plant distribution.

Care of seedlings

As soon as the first seeds start germinating, remove the plastic cover. Too much moisture may favour the attack of fungi and bacteria that damage seedlings. However, during their first two weeks saguaro seedlings are not drought resistant, so they should receive frequent watering. It is important to find a compromise between providing enough water and preventing over watering. Water should be applied only when the soil surface begins to desiccate. Only a fraction of the seeds will germinate at the outset, but subsequent irrigations will lead to germination of more seeds (Fig. 3). Some outstanding saguaro seeds (i.e. less than 1%) may germinate one year after sowing (Fig. 4). The variability of seed germination periods is a key adaptation strategy for desert plants (Leopold, 1972). In fact, every time there is adequate rainfall, more seeds will germinate.

Figure 3. Saguaro seedlings ranging from one day to two weeks of age are growing on peat soil. Subsequent watering resulted in germination of new seeds (EC).

Figure 4. The arrow indicates a saguaro seed that germinated on sandy soil one year after sowing (EC).

The best location for the seedlings is a window ledge (not southern exposure). Bear in mind that you are attempting to reproduce the micro-environment found beneath the canopy of a nurse plant, which means diffuse light, and little or no direct sun. Ideally, your seedlings should receive about half an hour of direct sunlight per day, preferably early morning or late afternoon. On the other hand, if seedlings are allowed to receive merely diffuse light, they tend to develop delicate, soft tissue that could be easily damaged by insects, fungi or bacteria. At the age of about four weeks the seedlings have the appearance of miniature cacti. As soon as the seedlings develop a set of real spines (Fig. 5) they can withstand relatively long periods of drought. When your seedlings reach the age of 6-8 weeks you can leave your home, or office, for vacation or business without worries about irrigation. This is one reason why cacti make excellent apartment plants. However, survival is one thing, but growth is quite another. Despite the widely-held belief that "*cacti should receive only one tablespoon of water per month*", in order to achieve satisfactory growth, seedlings and juvenile plants should be irrigated generously

Figure 5. A uniform stand of saguaro seedlings at the age of two months has well developed first spines and can withstand periods of drought (EC).

throughout the growing season, normally from March until October. On the contrary, it is very important to keep the soil completely dry during fall and winter. It is during the cold season that too much water can easily damage the cacti.

In order to support growth, the saguaro seedlings can be fertilized about once a month during the growing period. Be aware that you should fertilize with parsimony, because the nutrient requirements for saguaro seedlings are quite modest. In fact, saguaro is well adapted to natural desert environments with little availability of nutrients. Use water soluble fertilizers for house plants, containing a mixture of nitrogen (N), phosphorous (P), potassium (K) and microelements. This fulfills the needs of every plant in every soil, and is quite practical because it does not leave undesired solid residues on the soil surface. In protected environments, under good watering and nutritional conditions, saguaro plants may reach 2.5 -3.0 cm height at the age of one year (Fig. 6); some outstanding plants may reach the height of about 5-7 cm at the age two years (Fig. 7). In contrast, but not in contradiction, Steenbergh and Lowe (1976) documented that saguaro seedlings in the wild reach 0.7 and 1.0 cm height at the age of 13 months and 26 months, respectively.

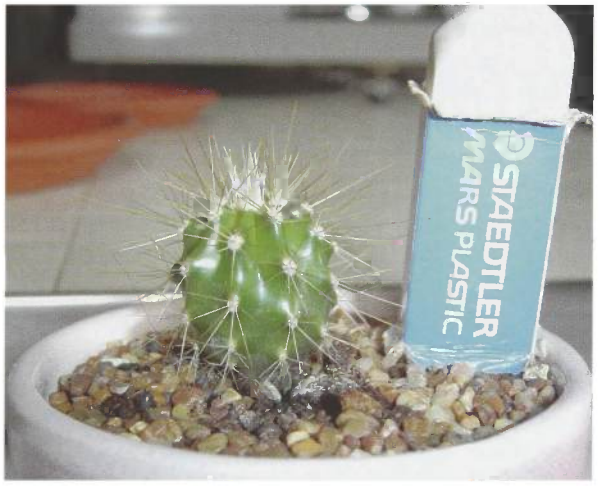

Figure 6. A saguaro seedling at the age of one year (EC).

Care of juvenile plants

In their second year, juvenile saguaros can be gradually exposed to more direct sunlight, and eventually moved outdoors during the growing period. Nevertheless, if the objective is to achieve fast growing plants, they should be kept indoors. It is important to stress that an abrupt move to full sun may result in epidermal burning. Moreover, it is important to consider that the extent of sun exposure has a profound effect on the general appearance. As a general rule, plants fully exposed to direct sunlight grow slowly, develop long and robust spines, a thick epidermis and overall a "wild" appearance. On the contrary, plants growing in shade tend to grow faster, develop soft and short spines, and an overall "gentle" appearance (Fig. 8).

Figure 7. Saguaro juvenile plant at the age of two years, grown indoors (EC).

As far as soils are concerned, juvenile plants are much more adaptable than seedlings. Although heavy textured, clay soils, should always be avoided, juvenile plants can adapt to many kinds of soils, providing that the pot provides good drainage.

Figure 8. Left: A juvenile saguaro exposed to direct sunlight developed long and robust spines and an overall "wild" appearance. Right: A juvenile saguaro grown indoors with diffuse sunlight, developed soft and short spines, and an overall "gentle" appearance (EC).

Transplantation

As soon as the plants start competing with each other for available space, usually about the end of the first year, they should be transplanted. Since transplantation causes inevitable root damage, transplanting should be done with the soil completely dry. After transplanting it is better to wait a few days before watering. Transplanting during the winter is ideal; since the plants are resting they can even be kept uprooted for months without any damage. At the age of one year the spines are developed, so the plants should be handled carefully.

For aesthetic and practical reasons, cacti are often cultivated in small pots. In their natural environment saguaros extend their root systems a distance corresponding to the plant height enabling them to collect rainfall from a relatively large area. It is important to compensate for the small area in a pot with frequent irrigations.

Over wintering

If you grow saguaros in locations where the temperatures goes below 0 °C frequently, it is necessary to bring your plants indoors during the winter (approximately November to April)(Fig. 9). A greenhouse is ideal but plants can be kept in a heated environment but not close to radiators. Apply no water, or very small amounts, during the winter.

In mild climates, where it freezes occasionally but thaws during the day, saguaros can be kept outdoors during the winter. However, even in their native environments, it is important to avoid northern exposures and shaded areas. Ideally, cultivate the plants in the vicinity of a sunny exposed brick wall. A south-facing wall can effectively protect your plant against cold winds and also provide some heating from nocturnal re-radiation of the sun received during the day (Fig. 10).

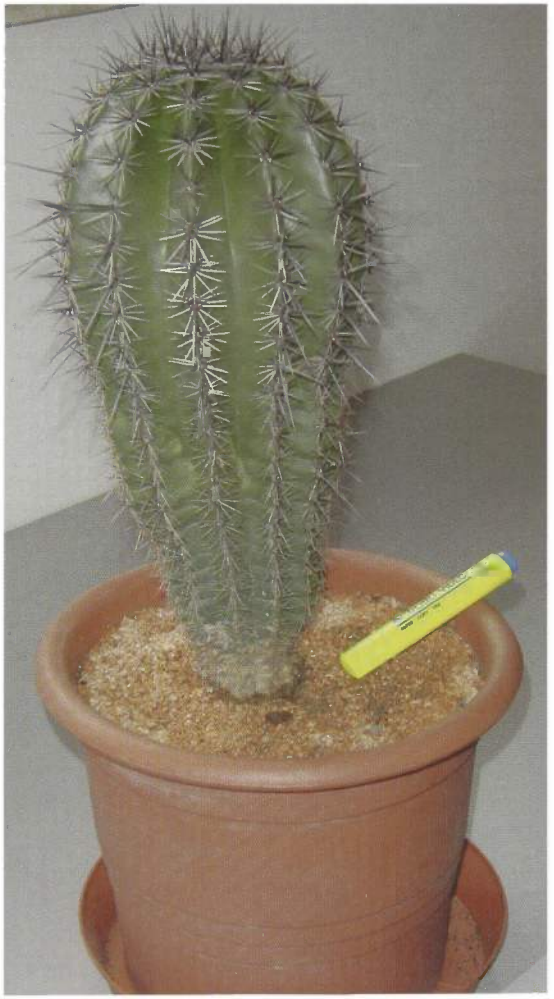

Figure 9. This juvenile saguaro is 18 years old and makes a good office plant during the winter period (EC).

Figure 10. A sunny exposed brick wall may effectively protect your saguaro during the winter (EC).

A way forward

Although adult saguaro plants are available commercially, saguaro is a protected species that shouldn't be removed from the native desert. Furthermore, the history of the saguaro population at the base of the Rincon Mountains provides evidence that this plant species may be dramatically endangered by climatic changes. Therefore, fostering saguaro cultivation from seeds may provide, in the long term, a strategic source of plants for gardening, for re-establishment in degraded desert areas and, eventually, for new establishment in areas with suitable climates. Climate scientists are convinced that in the future, extreme summer heat and drought will become the rule rather than the exception (Schiermeier 2008). This is likely to extend the area where saguaro can be cultivated successfully. Moreover, in many areas of the US and worldwide, the population pressure on freshwater supplies is increasingly high. In a world facing water-scarcity, fostering the spread of drought adapted plants for gardening can contribute to reducing water use by municipalities. Interestingly, Garvie (2006) highlighted that the atmospheric CO_2 embodied into the saguaro biomass, has a very long time of decay after the death of the plant. Consequently, the saguaro could provide a valuable contribution in enhancing carbon sequestration in arid areas.

There is an Italian proverb stating "planting olive trees (*Olea europea* L.) is a legacy for your children and planting walnut trees (*Juglans regia* L.) for your grandchildren". Featuring this proverb, I would say that growing saguaros is a legacy for your grandchildren, and also makes a contribution in a water-scarce world.

Bibiliography

Bowers, J.E. 2003. Frequently asked questions about the saguaro. Western National Parks Association: 20 pp.

Drezner, T.D. 2006. Plant facilitation in extreme environments: the non-random distribution of saguaro cacti (*Carnegiea gigantea*) under their nurse associates and the relationship to nurse architecture. Journal of Arid Environments 65: 46–61.

Garvie, L.A.J. 2006. Decay of cacti and carbon cycling. Naturwissenschaften, 93: 114–118.

Leopold, A.S. 1972. The Desert. Italian edition, Arnoldo Mondadori Editore: 191 pp.

MacAuliffe, J.R. 1993. Case Study of Research monitoring and management programs associated with the saguaro cactus (*Carnegiea gigantea*) at Saguaro National Monument. *Technical Report NPS/WRUA/NRTR-93/01*: 46 pp.

Nobel, P.S. 1988. Environmental biology of Agaves and Cacti. Cambridge University Press, UK: 270 pp.

Pierson, E.A. and Turner, R.M. 1998. An 85-year study of Saguaro (*Carnegiea gigantea*) demography. Ecology, 79 (8): 2676–2693.

Schiermeier, Q. 2008. A long dry summer. Nature, 452: 270-273.

Steenbergh, W. F., and Lowe, C. H. 1969. Critical factors during the first years of life of the saguaro (*Cereus giganteus*) at Saguaro National Monument, Arizona. Ecology, 50: 825–834.

Steenbergh, W. F. and Lowe, C. H. 1976. Ecology of the Saguaro: I: The Role of Freezing Weather in a Warm-Desert Plant Population. In Research in the Parks. Washington, DC: National Park Service, National Park Service Symposium Series No. 1: 49–92.

Steenbergh, W. F., and Lowe, C. H. 1977. Ecology of the Saguaro: II: reproduction, germination, establishment, growth, and survival of the young plant. National Park Service Scientific Monograph Series No. 8. Washington, DC: National Park Service: 226 pp.

Suggested website:
http://www.friendsofsaguaro.org

Editor's note...Researchers in Arizona have determined that using peat as a growing medium for long term cultivation of saguaros can result in root death.

Ongoing research at Boyce Thompson Arboretum