Transplantation of adult Argan trees (*Argania spinosa* L. Skeels)

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Received 11/11/2023
Accepted 19/129/2023

Abstract

Transplantation of adult Argan trees is an important option for the conservation of this Moroccan ecological heritage plant species, especially when the land has to be cleared for development purposes. Given that adult Argan trees' transplanting has not been investigated, this work was initiated to assess the success rate of this operation. The trees were removed from a rocky open cast cement quarry and planted in a deep soil located inside the premises of the cement plant. Two seasons were investigated, summer and winter of the year 2020. Tree preparation consisted of different canopy pruning, ranging from complete cut back to light trimming for global shaping; and proper root pruning. Regular watering was applied to the transplanted trees and gravel mulch placed on the surface of the watering pans to conserve soil moisture. The results show that Argan trees transplanted in summer resulted in 62.5% recovery, whereas those transplanted in winter reached 50%. Total branches removal (trees cut back) resulted in the highest rates of recovery independently of the season.

Keywords: Adult Argan trees, Pruning, Bare roots, Transplantation, Summer, Winter

INTRODUCTION

The Argan tree is a thermophilic and xerophilic species endemic to Morocco. The majority of the Argan woodland is located in the infra-Mediterranean bioclimatic range with semi-arid and arid bioclimatic variants, along the Atlantic coast. The Argan tree is sensitive to frost and is therefore eliminated if temperatures below 0°C persist. It only tolerates negative temperatures if they are of short duration. On the other hand, it remarkably tolerates high temperatures, which can reach 50°C in the region of Taroudant (Morocco). It is a tree resistant to long periods of drought and to the drying effects of the wind (Msanda *et al.*, 2005). The Argan tree can withstand drought because to its ability to draw water from the soil even in advanced drying conditions and because its trunk and branches are probably water reservoirs that help limit the diurnal decline of foliage water potential, thus allowing it to escape severe water stress (Msanda *et al.*, 2005). Its root system, which can cover areas of up to 60 m² and more, is also a fundamental element that allows it to withstand long periods of drought (Msanda *et al.*, 2005). It is known that the Argan tree has a deep-rooted system, which can go down to great depths.

Research on the Argan tree is quite prolific. Several scientific articles and theses have been published by local and international researchers. The work done so far has focused on the biology and physiology of the tree under normal conditions and under stress, as well as aspects related to its genetics. To our knowledge, no structured research has been reported on the transplantation of adult Argan trees and on the success rate of this operation. Yet, transplanting adult trees remains one of the affordable means for the conservation of this Moroccan heritage species in the event that an Argan tree populated land must be cleared for development purposes or to serve other uses. This is the case of a cement plant that has obtained a concession in the Moroccan Anti-Atlas Mountain to extract the rocks necessary for cement production. Given the open cast extraction mode, the existing Argan trees on the exploitable site were doomed to destruction. The cement company's environmental awareness led it to get involved in this research with the aim of transplanting Argan trees from the extraction quarry to a replanting site inside the factory located in a flat land at the foot of the Anti-Atlas Mountain not far from the extraction site.

Transplantation is a technique that involves digging up a plant that was growing in one place and planting it in another. Most often, the plant starts from a seed in optimal conditions (greenhouse nurseries) and then is replanted in another location (transplanting), usually outdoors (Vandergriff and Clatterbuck, 1995). However, transplantation is also the term used to describe the excavation of plants naturally growing in one site and replanting them in another (Starbuck *et al.*, 2005). The part of the root system lost when the tree is uprooted must be replaced for establishment in its new location. When it comes to saving a condemned adult tree due to the redevelopment of its environment, it is imperative to plan ahead for the operation (Starbuck *et al.*, 2005). The transplantation of some particularly valuable plants must be carefully done because it carries a high risk of failure (Pryor, 2014). Moving a tree can preserve an ageless witness that is no longer desired in the place it occupied (Richardson-Calfee and Harris, 2005). According to Pittenger *et al.* (2005), if the roots of a transplanted plant are buried more than 15 cm below the level they were, there is a greater risk of recovery failure. Similarly, the arrangement of roots above the ground level can reduce the capacity for root regeneration (Alphandéry, 1995).

Root pruning in advance can have beneficial effects provided it has not been carried out during periods of active shoot growth. The longer the time between root pruning

https://doi.org/10.5281/zenodo.10407923

and transplanting, the more likely the roots will develop and establish (Pryor and Watson, 2016). In some cases, all roots of the transplanted plants were pruned to ensure better root initiation capacity after transplantation, especially for the small diameter roots which seemed to have the best aptitude for recovery (Levinsson, 2013).

Transplanting periods and especially seasons can have a significant effect on tree recovery. Therefore, the time to undertake this operation should coincide with ideal seasonal conditions (Richardson-Calfee and Harris, 2005). Deciduous trees are generally transplanted during the season of vegetative dormancy, from November to March. The best time to transplant a tree is during its dormancy phase, making sure that soil conditions are tolerable (Richardson-Calfee and Harris, 2005). Special management after transplantation may be necessary if trees are transplanted at unfavorable times (Richardson-Calfee and Harris, 2005). Studies have shown that deciduous trees transplanted during their dormancy self-regulate water loss by reducing leaf surface transpiration during the season following replanting and can transpire at lower rates than non-transplanted trees (Kjelgren and Cleveland, 1994). This is due to a reduced leaf surface (thus less transpiration) which reduces total water loss and exerts a lower demand on the root system.

Root development is sensitive to soil temperature, moisture and/or the plant's stress level. If the stored carbohydrates are exhausted before being replenished from photosynthesis, itself depending on water uptake, transplanted plants can die. The part of the root system lost when the tree is uprooted must be replaced so that it can establish itself in its new location. When it comes to recovering adult trees due to the redevelopment of their environment, it is imperative to provide preparation in advance (Starbuck *et al.*, 2005). A large tree that has never been transplanted has less chance of recovery than a tree grown in a nursery because the latter, having undergone one or several transplants, has a developed root system close to the trunk. And the older the trees are, the less developed their ability to recover after transplantation (Arnold, 2005).Constraints at the replanting site influence root growth, mainly low soil temperatures and low humidity. Reducing these constraints lies in eliminating competing weeds that make available water less accessible and in choosing the adequate season. Survival depends on the ability of the transplanted tree roots to withstand growth conditions and to restore sufficient access to water before the stored carbohydrates are exhausted (Rietveld, 1989).

Post-transplantation monitoring and care are essential. Stress symptoms should be monitored for 2 years after transplantation to help the trees cope with drought (Miyasaka and Hamasaki, 2016). Optimal growth seems to be associated with the species' preference for the habitat to which they are associated. Species that adapt and increase their growth in response to irrigation are generally native plants (Miyasaka and Hamasaki, 2016).

Most trees that survive transplanting develop an extensive root system, capable of supporting severe soil conditions. Rapid regeneration of the root system of transplanted trees is essential for survival and recovery. Mulching the soil around trees is an important factor that increases root growth by reducing or eliminating competition from weeds and helping to maintain adequate moisture and aeration in the topsoil layer (Watson and Himelick, 1982).

This article reports on the first results of a structured research on mature Argan trees transplantation undertaken within the Argan ecosystem because trees were intended to be destroyed to allow the extraction of rock for cement production.

MATERIALS AND METHODS

Transplantation seasons

In this trial, 2 seasons were studied: summer and winter of the year 2020. The summer transplantation was carried out during the month of July over a period of 15 days. In fact, the scheduled date for the transplantation coincided with an episode of excessive heat (47°C were measured at midday) and operations were suspended until the end of the heat wave. The winter transplantation was carried out at the end of December 2020 over a period of 5 days.

Trees preparation for transplanting

Argan trees intended to be transplanted have been identified at the extraction quarry site (Coordinates 30.205° Northern latitude; 9.067° Western longitude).These trees occupied the space that needed to be cleared for rock exploitation. They had variable morphological aspects and obviously were of different ages. Some had large stems with well-stocked crowns; others had canopies on several stems whereas others were prostrate forming a mass of branches and foliage at ground level. To evaluate the effect of canopy reduction on recovery after transplanting, Argan trees underwent different types of pruning which also facilitated their handling during the transplantation process (digging, uprooting, transport and planting in the receptor site). The kinds of pruning were applied according to the shape of each tree. They involved either trimming the specimen to reduce overgrowth or pruning to bring it to a balanced shape or completely cutting back the branches leaving only the trunk or trunk with some scaffolding branches. As the shapes were very variable, it was difficult to apply the treatments to comparable numbers of trees. For each season, 40 Argan trees were transplanted in total. It should be noted that before extracting the plants, the side facing north was indicated by a paint mark in order to keep the same orientation at the time of planting. Before excavating the trees in the quarry, one cubic meter (1 x 1 x 1 m) planting holes were prepared at the replanting site inside the cement plant (Coordinates 30.237° Northern latitude; 9,041 Western longitude). They were partially filled with top soil and abundantly watered before receiving the Argan tree transplants.

The preparation of the trees was done by applying 3 treatments for the 2 transplanting seasons. During summer transplantation (July 2020), 25 trees were cut back, 11 pruned and 4 trimmed while for the winter operation

(December 2020), 13 plants were cut back, 14 pruned and 13 trimmed (Table 1). Given the rocky nature of the soil in the quarry site, it was impossible to extract the trees with root balls. Therefore, all Argan trees were transplanted with bare roots that were carefully and properly sectioned to reduce fraying and prevent disease entry through indentations.

Once the Argan trees were put in the planting holes, top soil was put back and well packed around the roots to ensure good adherence and anchoring of the plants. Following each planting, the transplants received copious watering. Subsequently, regular watering was applied according to the requirements. Mulch made of gravel was applied to cover *impluviums*, basins made around the transplanted trees to contain irrigation water. These *impluviums* were weeded as required to prevent any competition for water between the transplanted trees and weeds.

Quarry and reception site soil characteristics

The soil on which the Argan trees grow in the quarry and in the reception site was analyzed for characterization. In the quarry, top soil was sampled at the available depth (ca. 30 cm) because of the presence of a rocky bed. In the reception site, the soil was deeper and 2 horizons were sampled: 0-30 cm (H1) and 30-100 cm (H2).

Soil moisture at field capacity (FC) and permanent wilting point (PWP) and therefore the available water content (AWC) and the readily available moisture were calculated for the reception site soil using the formula developed by Saxton and Rawls (2006). Based on organic matter (OM) content and soil particles (clay, silt and sand), humidity at field capacity of the soil was determined (water retention capacity). It mainly depends on soil particle size and represents the maximum amount of water it can hold within its pores without any excess. The permanent wilting point is the humidity level below which the plant no longer has access to water, because it is so bound to the soil that the roots cannot overcome the water retention forces (Veihmeyer and Hendrickson, 1931). The available moisture is the amount of water (in mm) which is between FC and PWP. The following equation was used to determine soil moisture based on weight (Veihmeyer and Hendrickson, 1931):

$$\text{Hm}\ (\omega) = (\text{mass of water}/\text{mass of dry soil}) \times 100 \qquad (1)$$

The water retention capacity or field capacity corresponds to the available moisture + the water not accessible to plants. The available moisture varies according to the soil type from 1/3 to 2/3 of the retention capacity in sandy and clay soils respectively. Using the software SPAW Hydrology (United States Department of Agriculture - NRCS), soil water intervals were determined (especially the readily available moisture) based on particle size and OM (Saxton and Rawls, 2006).

Irrigation water characteristics

After transplantation, the Argan trees were watered with a tanker truck supplying water from a well dug in a nearby farm. This source was identified and water analyzed for characterization. Soil and water analyses were carried out in the soil sciences laboratory of the Hassan 2nd Institute of Agronomy and Veterinary Medicine (Agadir) using standard soil and water analyses methods. Rainfall and other meteorological data were obtained from a weather station belonging to a farm located at 6 km from the experimental site.

Recovery and growth monitoring

Regular monitoring was carried out to evaluate the survival of Argan trees through the observation of recovery signs (bud bursting, leaf formation, twig growth and elongation). Since the Argan trees transplants had very varied shapes and aspects, the elongation of a randomly selected twig in each plant was measured on a monthly basis. In addition, the Growth Index (GI) (Montague and Fox, 2008) was applied to assess changes in the stem. The GI represents the increase in growth that has occurred between planting and moment "t". It is calculated as follows (Griffin *et al.*, 2010):

$$\text{GI} = (\text{Greater stem width} + \text{Smaller stem width} + \text{Stem height})/3 \qquad (2)$$

In order to follow the total variation of the GI since the beginning of the experiment, the Relative Growth Index (RGI) related to each measurement date is determined as follows (Griffin *et al.*, 2010):

$$\text{RGI} = [\text{GI}(t) - \text{GI}(\text{initial})]/\text{GI}(\text{initial}) \qquad (3)$$

Regular monitoring allowed the assessment of the recovery rate and twig growth of the transplanted adult Argan trees. Statistical analysis was carried out using IBM SPSS Statistics 25 software.

Table 1: Number of transplanted Argan trees according to shape and season

Treatment	Overall trees shape	Summer transplantation	Winter transplantation	Total
Cut back	Single stem (SS)	23	3	26
	Branched shrub (BS)	1	0	1
	Multiple stems on stump (MS)	1	10	11
Pruned	Single stem (SS)	8	4	12
	Branched stem (BS)	0	7	7
	Multiple stems on stump (MS)	3	3	6
Trimmed	Single stem (SS)	0	0	0
	Branched shrub (BS)	4	12	16
	Multiple stems on stump (MS)	0	1	1

RESULTS

Soil and irrigation water characteristics

The physicochemical characteristics of the soil in the quarry and in the reception site are presented in Tables 2a and 2b. Irrigation water characteristics are shown in Table 3.

The soil in the reception site is sandy-loam with organic matter content below the 2 % recommended value (Table 2a). The pH is alkaline but the EC is low. The content in calcium is very high explaining the alkaline pH. The other elements are present in proportions that are in accordance with the Souss plain. Water availability is relatively low, not exceeding 11 %.

The soil in the quarry has a similar composition as the soil in the reception site: sandy-loam texture, low EC, alkaline pH and normal organic matter and mineral contents (Table 2b). Water availability is close to that of the reception site (11.7 %).

The water used for irrigating the transplanted Argan trees has a neutral pH and a low EC. Except for calcium and magnesium, all mineral elements are in rather low concentrations (Table 3).

Climatic conditions during the experimental period

The climatic conditions that prevailed between July 2020 and February 2022 are presented in Table 4. The data relate to precipitation, reference evapotranspiration, temperature, and air relative humidity.

During the experimental period, the climate data are those of an average year in terms of rainfall: 135 mm from July to December in 2020 and 260 mm in 2021 (Table 4). Substantial rain fell from October to February but without any consistency, illustrating the irregularity of the local climate. Average monthly maximum temperatures fluctuated from 21°C in winter to 35°C in summer. Average monthly minimum temperatures fluctuated between 5°C in winter and 19°C in summer (Table 4). Relative humidity of the air (RH) was rather high on average. Average monthly maximum RH was higher than 80% whereas average monthly minimum RH fluctuated between 27 and 55%. Reference evapotranspiration was relatively high: 850 mm between July and December 2020 and 1712 mm during 2021.

Table 2a: Physicochemical properties of the soil in the reception site

Parameters	H1 (0-30 cm)	H2 (30-100 cm)
Clay	10.0%	14.4%
Fine silt	18.8%	20.1%
Coarse silt	13.3%	13.1%
Fine sand	0.50%	0.20%
Coarse sand	57.4%	52.2%
Organic matter	1.36%	1.57%
pH	8.22	8.45
EC	0.17 dS/m	0.21 dS/m
Ca	1598 ppm	1778 ppm
Mg	48.4 ppm	59.6 ppm
K	32.4 ppm	41.1 ppm
NO_3^-	32.9 ppm	39.1 ppm
Mn	0.14 ppm	0.2 ppm
Na	59.7 ppm	62.2 ppm
Fe	1.6 ppm	2.4 ppm
Zn	0.01 ppm	0.012 ppm
Cu	0.127 ppm	0.196 ppm
Bulk density	1.53 g/cm^3	
Saturation	42.8%	
FC	22.2%	
PWP	11.4%	

Table 2b: Physicochemical properties of the soil in the extraction site

Clay	17.4%	**EC**	0.14 dS/m
Fine silt	15.6%	**pH**	8.54
Coarse silt	10.9%	**Ca**	264 ppm
Fine sand	2.6%	**Mg**	29.7 ppm
Coarse sand	53.5%	**Na**	14.3 ppm
Organic matter	1.6%	**K**	18.5 ppm
Bulk density	1.45 g/cm^3	**Mn**	0.12 ppm
Saturation	44.8%	**Cu**	0.08 ppm
FC	21.6%	**Fe**	0.73 ppm
PWP	9.9%	**Zn**	0.22 ppm

Table 3: Characteristics of the water used for the irrigation of transplanted Argan trees

EC	pH	Ca	Mg	K	Na	NO_3^-	Cl^-	CO_3^{2-}	P	Trace elements
dS/m		*ppm*								
0.72	7.08	95.4	37.4	4.68	10.8	28.5	15.0	41.1	Trace	Trace

Table 4: Climatic conditions between July 2020 and February 2022

Year	Month	Precipitation (mm)	ET0 (mm)	Temperature (°C)			Air Relative Humidity (%)		
				Av. max.	Av. mean	Av. min.	Av. max.	Av. mean	Av. min.
2020	July	0	161.0	35.2	25.7	19.2	97.7	72.1	40.4
	August	3	185.5	35.6	26.3	19.1	91.1	65.9	38.2
	September	5	157.0	32.8	23.8	16.9	96.4	71.8	40.9
	October	19	136.2	28.8	19.8	12.5	95.8	73.5	41.3
	November	102	111.4	26.7	18.2	11.2	93.9	69.6	37.7
	December	6.5	97.9	21.9	14.3	07.5	96.4	77.6	46.4
2021	January	87	96.0	21.0	13.2	06.5	99.4	82.4	50.4
	February	58	98.6	21.4	14.2	07.6	99.4	83.0	54.7
	March	10.5	157.2	25.5	17.2	09.3	95.3	68.1	36.2
	April	6.2	145.0	24.9	18.1	11.6	99.8	81.1	51.4
	May	32	155.9	27.9	19.9	13.3	99.9	79.1	49.9
	June	10	175.9	29.5	21.3	14.4	98.5	76.8	47.8
	July	2	192.0	34.8	24.9	17.2	96.6	71.1	40.1
	August	3.6	177.4	32.5	24.5	16.6	96.3	75.6	45.9
	September	0	155.0	31.8	23.9	16.1	98.2	74.9	42.8
	October	0	158.5	31.6	21.6	12.4	98.4	63.1	31.2
	November	45	89.2	22.7	15.0	08.4	99.8	82.0	48.9
	December	5	111.4	24.9	14.9	04.9	83.0	52.1	27.7
2022	January	16	109.7	23.7	15.4	07.1	81.6	56.4	28.6
	February	0	113.2	25.4	17.5	10.3	79.4	55.4	33.1

Recovery of adult Argan trees transplanted in summer and in winter

Tables 5a and 5b show the recovery rate of the adult Argan trees transplanted in summer and winter respectively, according to their overall shape and applied treatments.

The Argan trees transplanted in summer resulted in a recovery rate of 62.5 % on average (Table 5a). However, the cut back trees had a higher rate of recovery in comparison with the other treatments: 76 % compared to 45 and 25 % for the pruned and trimmed trees respectively. In winter, the transplanted Argan trees had a lower recovery rate on average (50%) but those that were cut back had a high rate of recovery reaching almost 85% (Table 5b). The pruned and trimmed trees had lower recovery rates (21 and 46 % respectively). The statistical analysis carried out showed that the studied factors did not have any significant effect on recovery.

Development monitoring of the transplanted Argan trees

Table 6 shows the twig lengths reached between transplanting in summer and winter 2020 and March 2022. In both seasons, the trees that were cut back had taller twigs than those that were pruned or trimmed. Their twigs were three times as long as the pruned trees and clearly longer than the trimmed ones. Nevertheless, the high values of the standard deviations do not allow distinguishing any statistically significant differences.

Figures 1 and 2 show the patterns of twig elongation according to the treatments undergone by the Argan trees prior to transplanting. The general trends were linear for both seasons and types of tree's shaping. The equations indicate the slope for each type of pruning. Both in summer and winter, the twigs from cut back trees had higher values and steeper slopes, followed by the trimmed and the pruned ones.

Table 5a: Recovery rate of adult Argan trees transplanted in summer (as at the end of March 2022)

Treatment	Trees shape	Trees number	Recovered trees	Recovery rate (%)	Total rate (%)
Cut back	SS	23	18	78.3	76.0
	BS	1	0	00.0	
	MS	1	1	100.0	
Pruned	SS	8	4	50.0	45.4
	MS	3	1	33.3	
Trimmed	BS	4	1	25.0	25.0
Total		40	25	62.5	62.5

Table 5b: Recovery rate of adult Argan trees transplanted in winter (as at the end of March 2022)

Treatment	Trees shape	Trees number	Recovered trees	Recovery rate (%)	Total rate (%)
Cut back	SS	3	3	100.0	84.6
	MS	10	8	80.0	
Pruned	SS	4	1	25.0	21.4
	BS	7	1	14.3	
	MS	3	1	33.3	
Trimmed	BS	12	5	41.7	46.1
	MS	1	1	100.0	
Total		40	20	50.0	50.0

SS = Single stem; BS = Branched shrub; MS = Multiple stems

Table 6: Twig lengths of the transplanted Argan trees 18 and 14 months after summer and winter transplantations

Summer transplantation	Twig length (cm)	Standard deviation
Cut back	82.5	50.8
Pruned	25.6	51.2
Trimmed	52.9	53.2

Winter transplantation	Twig length (cm)	Standard deviation
Cut back	59.1	40.8
Pruned	18.2	23.4
Trimmed	44.3	42.4

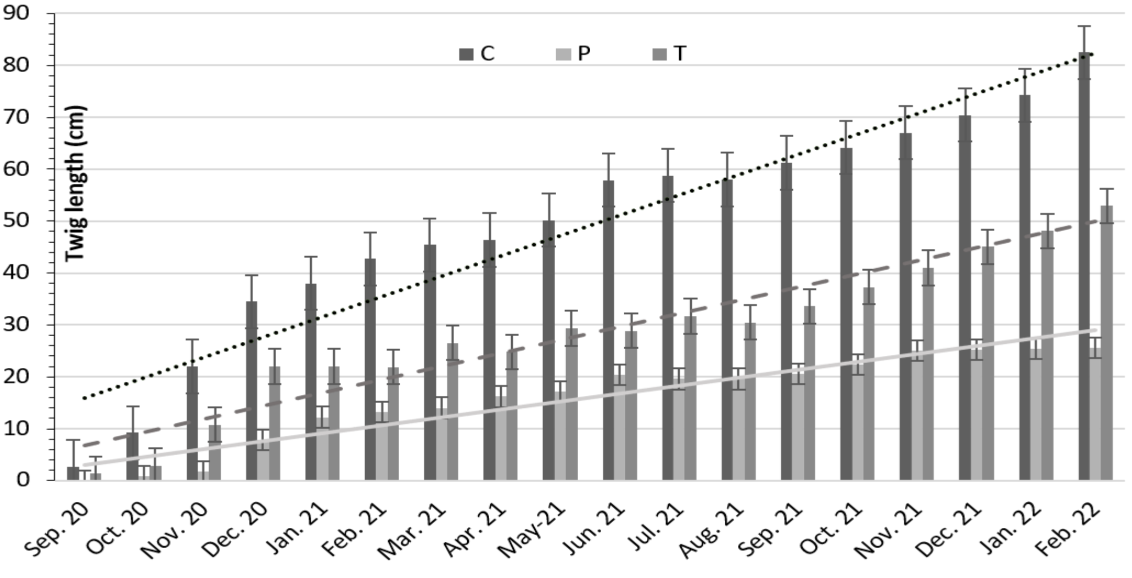

Figure 1: Evolution of average twig lengths of summer transplanted Argan trees from transplanting to February 2022 (C: cut back; P: pruned; T: trimmed), **C: $y = 3.91 x + 12.0$; P: $y = 1.53 x + 1.41$; T: $y = 2.55 x + 4.14$**

The relative growth index (RGI) of summer transplanted Argan trees was positive for the cut back but negative for those that were pruned and trimmed (Table 7a). In the winter transplanted trees, RGI was negative for all types of treatments. In spite of these different figures, no significant differences could be noticed because of high variations (Tables 7a and 7b).

Table 7a: Average RGI of the Argan trees transplanted in summer

Treatment	Average RGI	Standard deviation
Cutback	0.00575	0.28433
Pruned	-0.26932	0.12395
Trimmed	-0.01113	0.33612

Table 7b: Average RGI of the Argan trees transplanted in winter

Treatment	Average RGI	Standard deviation
Cut back	-0.29125	0.18858
Pruned	-0.35623	0.27657
Trimmed	-0.52433	0.31927

DISCUSSION

The Argan ecosystem is among the most important in Morocco because of its peculiar existence in an arid context contrasting with the rest of territories at this latitude. The low rainfall is compensated by air humidity provided thanks to the proximity of the Atlantic Ocean. The Argan is a multipurpose tree endemic to Morocco that plays major ecological and economic roles. As such it is considered as a symbolic heritage tree and therefore its conservation is of great importance. It is in this scope that this study was carried out to investigate the potential for the recovery of adult Argan trees in the case of the implementation of development projects in a wooded land. In the present case, a cement factory has decided to undertake the transplanting of adult Argan trees from its authorized quarry site and plant them in the premises of its factory. As shown in the results, the soil is shallow in the mountains where rock outcrops are the predominant landscape, which obviously justified the location of the limestone quarry. The cement factory is located in the plain at the foot of the Anti-Atlas Mountains where the soil is deep, exceeding 1 m. Nevertheless, in both situations the soil is sandy-loam with rather acceptable agronomic characteristics for crops that are not sensitive to alkalinity. Miyasaka and Hamasaki (2016) observed that optimal growth seems to be associated with the species' preference for their natural habitat. Species that adapt and increase their growth in response to irrigation are generally native plants (Miyasaka and Hamasaki, 2016). In order to guarantee the recovery of tree transplantation, soil porosity and its air content as well as its water retention capacity and availability are of great importance (Caron and Kjelgren 2016). The predominance of the sandy and coarse silt fractions (≈70%) in the soil is an asset for optimal porosity, while the combination of fine silt and clay are valuable for water retention so important in arid conditions. Water analyses showed that it is of good quality for irrigation; especially the low EC. The climatic conditions reported are typical of a Mediterranean context with low rainfall; occurring during the winter season. The recorded rain was insufficient to meet the requirements of the transplanted Argan trees, hence the need for additional irrigation. Water was supplied at a 15-days frequency during the dry and hot periods, and once a month during the cooler ones. The climatic conditions were dry with evapotranspiration largely exceeding the amount of rain. However, the proximity of the ocean induced relatively high rates of relative humidity in the air.

The transplanting was carried out during summer and winter of 2020 applying three different preparations for the trees prior to extracting them. The results show that cutting back is the most effective treatment due to the recovery rates (Tables 5a and 5b), which resulted in 76 and 84.6% for the summer and winter transplantations

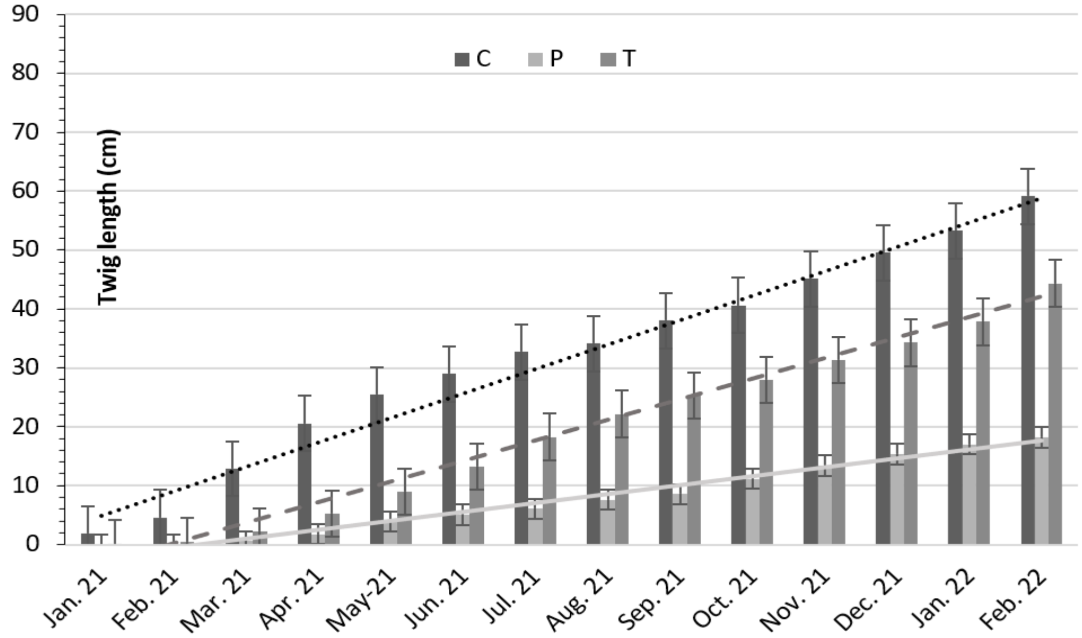

Figure 2: Evolution of average twig lengths of winter transplanted Argan trees from transplanting to February 2022 (C: cut back; P: pruned; T: trimmed) C: y = 4.148 x + 0.81; P: y = 1.51 x - 3.54; T: y = 3.49 x - 6.79

respectively. This can be explained by the elimination of the canopy thus tremendously cutting down the transpiration rate and therefore reducing water dependence during root production. Access to moisture is considered the main limiting factor for newly transplanted plants (Griffin *et al.*, 2010). In fact, as stated earlier, the Argan trees were transplanted bare rooted because of the rocky nature of the substrate at the quarry site. In the absence of original roots, the plant is subjected to drought conditions even when the soil is well watered (Griffin *et al.*, 2010). It has been explained that transplanted trees maintain a delicate balance between leaf area necessary for photosynthesis, the re-growth of roots in the soil, and the root volume necessary for water absorption. They balance the transpiration demand of the leaf surface with the root loss by reducing the number and size of the leaves, particularly in trees that have a large root loss (Caron and Kjelgren, 2016). In the case of the cut back Argan trees, the entire canopy was removed thus eliminating any transpiration through the leaves and keeping soil moisture for root regeneration.

In dry environments where regular watering is necessary, transplanted trees need less water quantity depending on the leaf area but require more frequent watering to keep the soil moist allowing the nourishment of the smaller root system and the formation of new roots (Kjelgren and Cleveland, 1994). Watson and Himelick (1982) reported that most trees surviving transplantation develop a significant root system able to tolerate rather severe soil environmental conditions. The rapid regeneration of the root system of transplanted trees is essential for survival and recovery. Water deficits often develop because the natural balance between the absorbing root surface and the transpiring leaf surface is disrupted (Montague and Fox, 2008). Therefore the recovery rate is improved depending on the leaf surface eliminated. Some studies support the general recommendation to reduce the canopy at the time of transplantation, since the tree compensates for the loss of roots by producing less leaf surface. In addition, the reduction in leaf area balances carbon assimilation with the production of new roots and the restoration of the tree (Kjelgren and Cleveland, 1994). However, growth may be reduced during dry periods, mainly due to the weakness of the root system, but also due to the slowing of photosynthesis (Kjelgren and Cleveland, 1994). If irrigation is not sufficient under dry conditions, reducing the crown size results in the transplanted trees needing less water to balance the loss of roots, which in turn helps reduce water stress after transplantation (Kjelgren and Cleveland, 1994). The reduction of the canopy size is a treatment that allows to increase the recovery rate, but Dagit and Downer (2002) noticed that 5 years after transplantation, fewer pruned trees were stable or in good condition and more trees were dead compared to the condition of the unpruned ones. Even 10 years after transplanting, the pruned trees had not regained the vigour they had before transplanting (Dagit and Downer, 2002). Therefore, it is essential to continue monitoring the Argan trees transplanted for several years to assess the extent to which the recovered trees have become irreversibly vigorous. Miyasaka and Hamasaki (2016) specified that post-transplantation monitoring and care are extremely important, and stress symptoms should be monitored for 2 years after transplantation to help the trees overcome it. In the subtropical climate of North Florida (USDA zone 10), trees were established at approximately one year for a 100 mm trunk diameter after transplantation (Beeson and Gilman,1992). Dagit and Downer (2002) reported that hot and humid soils and moderate air temperatures (low transpiration) are optimal for rapid root growth and minimized stress, resulting in successful transplantation. It has been stated that the success of transplantation also depends on the particular care given to the root system to ensure its development and adequate branching (Mimouni, 2019).

In these experiments, the summer season resulted in higher recovery rates for the transplantation of the Argan trees. This can be explained by the dormant state in which most Argan trees are during the driest periods of the year. Diaz-Barradas *et al.* (2010) reported that Argan trees shed their leaves in summer as an adaptation to drought stress. However, Harris and Bassuk (1993) reported that deciduous trees that are transplanted in dormant conditions should only be pruned for corrective reasons.

Shoot development after transplantation is a sign of recovery. New bud production and twig elongation are indicators of plant growth (Dostalek *et al.*, 2009). Their dynamics depend on the water status of the trees. If the moisture in the soil is sufficient, development will be continuous and maintained. In this study, twig length was higher in the cut back Argan trees compared with the pruned and trimmed ones. This can be explained by the fact that the cut back trees used most of their energy to produce new twigs that elongated quickly, acting as suckers. On the other hand, the pruned and trimmed Argan trees continued to use energy for the maintenance of activity through the remaining branches and leaves and therefore, the newly produced carbohydrates had to be shared between the old shoots and the newly produced buds and twigs. However, values of the relative growth index (RGI) were negative for the pruned and trimmed trees in the summer transplantation and for all treatments in the winter transplantation. The negative values suggest that the new growth was accomplished at the expense of the stored nutrients in the trees (Solfjeld and Hansen, 2004). This can be explained for the winter transplantation by the fact that during the cool season, the Argan trees were probably dormant and had to use their reserves to assure new root and shoot production. The root to shoot ratio is an expression of the physical and physiological balance between the root system and the canopy. Trees with low root/shoot ratios have generally less chance of surviving transplantation compared to those with higher root-shoot ratios (Beeson and Gilman,1992) which could further explain the rates of recovery recorded: the fewer the shoots on the crown, the higher is the ratio between roots and shoots.

Reducing soil moisture loss is one of the benefits of mulch application. Several researchers confirm that transplanted trees surrounded by organic mulch have improved shoot and root growth (Montague and Fox, 2008). Furthermore, when mulching is done, increasing the frequency of watering is more effective than applying larger volumes of water, which are rarely beneficial to transplanted trees (Griffin *et al.*, 2010). It seems that there is a maximum volume of watering necessary for the plant's functions (if applied properly) beyond which there is no additional benefit for the plant (Griffin *et al.*, 2010).

According to Watson (2005), the planting hole should be prepared one week in advance, have an opening larger than the size of the root ball and the soil should be enriched with compost and organic fertilizer. Before the transplantation process begins, it is important to ensure that the plant is well hydrated. In our study, the planting holes (approximately 1 m^3) were prepared inside the factory one day before or the same day of the transplantation, making sure that root burial is at the same depth they were in their original site (Dagit and Downer, 1997). Pryor (2014) found that rooting is significantly correlated with root diameter and the way they were cut. However, according to Griffin *et al.* (2010), root pruning during active shoot growth can reduce root regeneration (probably due to competition for carbohydrates reserves) and should be avoided. It should be noted that large trees take more time to produce a root system that is comparable to its original size (Harris *et al.*, 2002). When roots are cut, it takes 6 to 49 days for new ones to form (Watson, 2005). This was probably the case in the present study since all trees were transplanted bare rooted with roots severely pruned.

CONCLUSION

This study shows that it is possible to successfully transplant adult Argan trees and obtain substantial recovery rates. To adopt efficient and rational transplantation practices, it is necessary to understand the seasonal growth patterns of the trees and their reaction to digging up (Hensley, 1993) as well as the effects of manipulation during these operations. The failure of Argan tree transplanting may be due to the cool season or to active physiological period. Certain measures should be taken into consideration to increase the rate of recovery. This study shows that the summer season is better than winter for transplanting, regardless of the kind of pruning the trees underwent. Nonetheless, the complete removal of branches and leaves during winter transplantation enabled a recovery rate equivalent to summer. Other seasons (spring and autumn) should be tried so that we can have a complete idea about the optimal seasons for transplanting. Irrigation should be applied at a frequency that enables to keep the soil sufficiently moist for root production so that the tree is able to be self-sufficient once again (Yin *et al.*, 2017). The application of mineral and organic fertilizers has not shown any effect on the rate of recovery of Argan trees. At the transplantation stage, it is water that was a limiting factor for recovery (Watson, 2000) of newly transplanted plants (Griffin *et al.*, 2010).

Soil moisture monitoring is an approach that allows for more precise water use by measuring the drying rate of the soil. The installation of soil moisture sensors could be crucial for post-transplantation irrigation so that effective control and scheduling are achieved. Such devices will enable the reduction of water use and hence the direct costs associated with irrigation (Griffin *et al.*, 2010). Furthermore, the best way to immediately and efficiently meet the water requirements is to install a drip irrigation network that would allow watering at any time with a set amount as soon as the sensors indicate a decline in soil moisture below the acceptable threshold.

Acknowledgments: *This work was carried out in the framework of a research project on adult Argan trees transplantation, in partnership with ANDZOA, Lafarge-Holcim Group-Morocco, IAV Hassan II and Agrotech. Authors acknowledge the inputs of Mr. Mohamed Doulhousn for technical assistance during soil and water analyses and of Prof. Lhoussaine Baamal for advising on statistical analyses.*

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