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Transplantation of Mature Argan Trees (*Argania spinosa* L. Skeels): Recovery Rate Optimization

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Abstract: The present study deals with the transplantation of mature Argan trees (*Argania spinosa* L. Skeels) and focuses on optimizing survival rates depending on the seasons, the type of shoot pruning applied to the trees and preconditioning treatments consisting of root pruningand watering for a few months before transplanting. So far, the transplantation of this species at the adult stage has not received enough attention in spite of its ecological and socio-economic importance for the regions where it thrives. The results obtained show that transplanting in summer, autumn and winter resulted in survival rates exceeding 50%. The Argan trees transplanted in spring hardly achieved 10% survival. However, the total cutback of the crown induced survival improvement that reached a rate greater than 70% for summer, autumn and winter, and 50% for spring. Watering alone or combined with root pruning for 6 months helped improve the recovery rate but only when carried out in autumn with transplantation in spring. On the other hand, when these pre-treatments were applied in the spring to transplant the trees in summer, the recovery rate was not improved.

Keywords: Argan tree; shoot pruning; root pruning; watering; transplantation; survival

1. Introduction

During the last decades, the preservation of endemic species has become a major concern on a global scale and Morocco is no exception, especially because of its important plant diversity which places it among the best-off countries in the Mediterranean [1]. The Argan tree (*Argania spinosa* L. Skeels) is endemic to Morocco known for its ecological, economic, and cultural importance [2]. However, the natural ecosystem of this species is threatened due to several factors such as overgrazing, deforestation and climate change [3]. In addition, economic development projects that are being established in its distribution area put more pressure on the Argan woodland. Efforts to plant seedlings grown from seeds are becoming more extensive to help reverse the deforestation trend, but little work has focused on transplanting adult Argan trees intended for destruction due to development projects (urban expansion, road works, industrial zones, agricultural projects, etc.). Subjected to these pressures, Arganwoodlands are experiencing a significant reduction both in terms of density and area [4]. To try and balance this trend of tree cover regression, the transplantation of adult Argan trees constitutes a conservation strategy aimed at reducing the rate of loss by replanting them in sites not subject to anthropogenic degradation activities. This will compensate for deforested areas and contribute to meet the requirements of sustainable development in the Argan ecosystem.

Transplanting adult trees is a complex process that requires adapted techniques to optimize the survival and growth of transplanted specimens. In this study, different techniques were used to

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evaluate their effect on recovery rates. [5](pp. 148–156) studied the effect of three types of shoot pruning on the success rate of adult Argan trees transplanted either in summer (July) or in winter (December). The study which constitutes one of the first works devoted to the transplantation of adult Argantrees enabled to conclude that severe pruning enabled the achievement of the best recovery rates whether in winter or summer. Although this study only looked at these two seasons, it concluded that the best time to transplant Argan trees should coincide with the tree's dormant phase (summer in particular). Preparing the trees by properly pruning the canopy and roots is an important step. Regular watering provides the necessary moisture to the soil and the application of mulch contributes to maintain it, thus reducing water consumption while promoting the growth of the roots of transplanted trees. The article also indicated that adult Argan trees transplanted in summer had a recovery rate of 62.5% while those transplanted in winter achieved a lower rate of no more than 50%. However, the study reported that trees cutback (total branch removal) resulted in the best recovery rates after transplantation, regardless of the season.

In the present work, the investigation deals with the transplantation of adult Argan trees in spring and autumn as well as the application of pre-treatments which consist of applying watering combined or not with root pruning for a few months prior to transplanting, with the aim of evaluating their effect on recovery rates. Horticultural literature reports that preconditioning trees improves recovery rates after transplantation [6]. The most commonly used preconditioning consists of pruning the roots to induce the formation of new rootlets before removing the tree [7].

Shoot pruning is a necessary operation if only to facilitate trees handling during uprooting, transport and planting. In addition to proper preparation of trees fortransplantation, other factors must be taken into consideration [8]. This in particular relates to the choice of the destination site (distance from uprooting site, soil quality, exposure, etc.), irrigation management and regular observation of the transplanted specimens to react as required in due course [6].

2. Materials and Methods

The Argan trees subjected to this study grew in degraded woodland in the Anti-Atlas Mountains granted to a cement factory for the extraction of rocks entering in cement manufacturing. Given the open-air mining method, the existing Argan trees on the exploitable site were doomed to destruction. The environmental awareness of the cement factory led it to get involved in this research with the aim of transplanting these Argan trees into a replanting site inside the factory located on a flat land at the foot of the Anti-Atlas Mountains, not far from the quarry site. An area of nearly 2.5 ha was dedicated to planting the Argan trees removed from the quarry whose coordinates are: 30.205° Northern latitude; 9.067° Western longitude; and 500 m Altitude. The planting site's coordinates are: 30.237° Northern latitude; 9,041° Western longitude; and 230 m Altitude). The two locations are at 4.3 km distance as the crow flies.

(**a**) (**b**)

Figure 1. Images of quarry & receptor site: (**a**) Argan trees in the quarrying site; (**b**) Receptor site inside the cement factory.

Argan trees intended for transplantation were identified on the quarry site. Two types of actions were undertaken: transplantation in spring and autumn to compare them with the results obtained for summer and winter [5], and preconditioning before transplantation.

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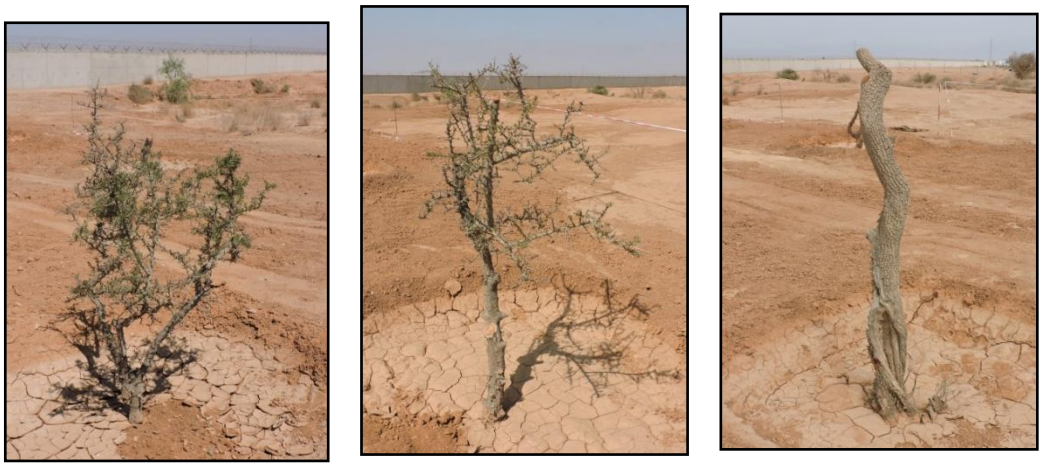
2.1. Transplanting in Spring and Autumn

Argan trees intended for transplanting were identified on the site of the quarry. These trees occupied the space that had to be cleared for rock mining. They presented variable morphological aspects with certainly different ages. Some had large stems with relatively lush crowns; others were composed of several stems while others were prostrate forming a mass of branches and foliage at ground level. To evaluate the effect of canopy reduction on recovery after transplantation, the Argan trees underwent different types of shoot pruning, which also facilitated their handling during the transplantation process (excavation, uprooting, transport and planting in the receptor site). Pruning types were applied according to the shape of each tree. They involved either trimming the specimen to reduce overgrowths, pruning it to achieve a balanced shape, or completely cutting off the branches, leaving only the trunk or trunk with a few structuring branches. The shapes being very variable, it was difficult to apply the treatments to a comparable number of trees. For the two seasons, a total of 72 Argan trees were transplanted. Before extracting the plants, the north face of the trunks was marked by a spray of paint in order to maintain the same orientation at the time of planting. Prior to removing the trees from the quarry, planting holes of approximately one cubic meter (1 x 1 x 1 m) were prepared at the replanting site inside the cement plant. This site, located in the Souss plain, has deep soil, enabling the digging into loose subsoil. The holes were partially filled with topsoil and watered abundantly before receiving the Argan trees.

As stated earlier, 3 types of shoot pruning were applied for the 2 transplanting seasons. During the spring transplant (April 2021), 14 trees were trimmed, 19 pruned and 6 cut back, while for the fall operation (September 2021), 12 plants were trimmed, 10 pruned and 11 cut back (Table 1). Given the rocky nature of the soil at the quarry site, it was impossible to extract the trees with root-balls. Therefore, all Argan trees were transplanted bare rooted. After uprooting, the roots were carefully sectioned to reduce fraying and reduce the risk of disease entry through wounds.

Table 1. Number of Argan trees transplanted according to pruning type for each season.

Pruning type Saison	Trimming	Pruning	Cut-back	Total
Spring (April 2021)	14	19	6	39
Autumn (Sept. 2021)	12	10	11	33



(**a**) (**b**) (**c**)

Figure 2. Treatments applied to argan trees: (**a**) Trimmed Argan tree; (**b**) Pruned Argan tree; (**c**) Cut back Argan tree.

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2.2. Preconditioning by Root Pruning and Watering

Argan trees intended for transplantation were chosen on land with enough soil to allow the operations to be carried out. They first underwent different shoot pruning as described for the spring and fall transplants. Subsequently, a 30 cm wide trench was dug all around at a distance of 80 cm to 1 m from the trunk and a depth of almost 30 cm (maximum depth due to the proximity of the hard rock). The roots encountered in the trench were carefully cut and the ditch was backfilled with soil amended with peat compost at a rate of 3 bags per tree (210 litres). Once the trench was filled in, a watering basin was formed and the tree adequately watered.

Given the particularity of the climatic context of the Argan ecosystem, characterized by prolonged droughts, in this work, in addition to root pruning, another preconditioning was tested consisting of applying regular watering before transplantation. For this, the candidate Argan trees were pruned as described above anda watering basin was formedaround the trees which were adequately watered.

Two preconditioning periods were tested: October and December 2020 as well as February 2021 for the trees to be transplanted in April 2021 and February and April 2021 for August 2021 transplantation. Watering of the Argan trees thus preconditioned has been applied once a month for 6, 4 and 2 months for transplants carried out in spring (April 2021) and for 6 and 4 months for summer transplants (August 2021). In April and August 2021, the preconditioned trees were carefully uprooted and the root ball wrapped in a woven cloth and secured with polyethylene strings. For each type of preconditioning, duration and period, 10 Argan trees constituted the experimental unit. There were also 18 trees used as controls during the April transplant and 12 during the August transplant.

As previously reported, the Argan trees subject to these pre-treatments presented varied shapes (erect, multi-stemmed, prostrate, etc.) and distinct physiological states (total absence of leaves due to drought or more dense foliage). The relatively higher numbers of control Argan trees compared to preconditioned ones were due to the fact that at the time of transplantation, they had to be evacuated in preparation for rock exploitation. Tables 2 and 3 summarize the numbers involved in these experiments.

Table 2. Number of Argan trees transplanted in April 2021 according to pre-treatments and shoot pruning types.

Pretreatment	**Root pruning and watering**			**Watering**			**Control**
Pruning type	6 months	4 months	2 months	6 months	4 months	2 months	-
Trimming	1	2	4	3	3	2	9
Pruning	1	3	4	2	3	3	5
Cut back	8	5	2	5	4	5	4
Total	10	10	10	10	10	10	18

Table 3. Number of Argan trees transplanted in August 2021 according to pre-treatments and shoot pruning types.

Pretreatment	**Root pruning and watering**		**Watering**		**Control**
Pruning type	6 months	4 months	6 months	4 months	-
Trimming	4	3	3	3	5
Pruning	3	3	3	4	4
Cut Back	3	4	4	3	3
Total	10	10	10	10	12

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(**a**) (**b**)

Figure 3. Pretreatments applied to argan trees: (**a**) Argan tree watered on the quarry site prior to transplanting; (**b**) Argan tree root pruning on the quarry site prior to transplanting.

2.3. Climatic Conditions

Climatic conditions, namely rainfall, temperature, relative air humidity and reference evapotranspiration (ET_0) were collected from the meteorological station at a farm located near the cement plant sites. This station is part of a network of stations established by AgroTech Souss-Massa, an association involved in assisting farmers for irrigation water management.

In 2021, the amount of rain was 259 mm distributed over 4 months (January, February, May and November); June to October was completely dry and the other months received less than 10 mm. The year 2022 was drier with only 192 mm, also distributed over 4 months but with great irregularity. December was the rainiest with 80 mm and January the driest in the rainy season with 16 mm, March and September were intermediate with 40 and 20 mm respectively. February, July and November were completely dry and the other months received less than 10 mm. The reference evapotranspiration (ET_0) was on average around 140 mm per month. It peaked at 220 mm in July 2022 (192 in 2021), the minimum being 89.2 mm in November 2021 and 83.4 in December 2022. The average annual temperature was 19.05 °C in 2021 and 20.22°C in 2022. The highest average maximum temperatures were recorded in July: 34.8°C in 2021 and 38.9°C in 2022.

2.4. Recovery Rate Monitoring

Regular monitoring enabled to assess the transplanted Argan trees survival. It consisted of watching for signs indicating recovery and growth: persistence of foliage on the plants, emergence of new buds, and elongation of branches. The observations lasted 3 years.

The statistical analysis was carried out by IBM SPSS Statistics 25 software at less than 5% significance level.

3. Results

3.1. Effect of Transplanting Season

Table 4 presents the recovery rates 2.5 years after transplantation (April 2024). It shows that spring did not enable high recovery rates. Only 10.25% of the Argan trees transplanted during this season did survive. On the other hand, in autumn, the recovery rate reached almost 60% (Table 4). It should be noted, however, that the total reduction of the crown gave the best recovery rates even in spring since 50% of the cut back Argan trees resumed growth. In autumn, the recovery rate of cut back Argan trees exceeded 70%.

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Table 4. Effect of season and type of shoot pruning on the recovery rate (%) of Argan trees after transplantation.

Shoot Pruning type / Saison	Trimming	Pruning	Cut-back	Average
Spring	07.14	0.00	50.00	10.25
Autumn	58.33	50.00	72.72	57.57

3.2. Effect of Argan Trees Preconditioning before Transplantation

Table 5 shows that 6 months preconditioning resulted in the best recovery rates compared to shorter periods and to the control trees. The application of watering alone for a period of 6 months made it possible to obtain a higher recovery rate than root pruning combined with watering for 6 months. However, control Argan trees had higher recovery rates compared to 2 and 4 months of preconditioning.

Table 5. Effect of preconditioning on recovery rate (%) of Argan trees transplanted in spring.

Pretreatment	Root pruning and watering			Watering			Control
Shoot Pruning type	6 months	4 months	2 months	6 months	4 months	2 months	
Trimming	0.00	0.00	25.00	33.33	0.00	50.00	33.33
Pruning	0.00	33.33	25.00	100.00	33.33	33.33	40.00
Cut back	75.00	20.00	50.00	80.00	25.00	40.00	75.00
Average	60.00	20.00	33.33	70.00	20.00	40.00	44.44

The results of preconditioning applied in February and April 2021 for transplantation in August 2021 are shown in Table 6. There is no particular trend, especially when compared to the control. Root pruning combined with watering during 6 months allowed the survival of 40% of the transplanted Argan trees. None of the trees watered during 6 months survived. On the other hand, watering for 4 months ended up with 30% survival of the Argan trees. Overall, Argan trees shoot pruning increased recovery rates.

Table 6. Effect of preconditioning on recovery rate (%) of Argan trees transplanted in summer.

Pretreatment	Root pruning and watering		Watering		Control
Shoot Pruning type	6 months	4 months	6 months	4 months	
Trimming	25.00	0.00	0.00	0.00	20.00
Pruning	33.33	0.00	0.00	50.00	25.00
Cut Back	66.66	25.00	0.00	33.33	33.33
Average	40.00	10.00	0.00	30.00	25.00

3.3. Statistical Analysis

Statistical analysis was carried out using IBM SPSS Statistics 25 software, referring to the GLM (Generalized Linear Model) method since it concerns qualitative data on the recovery of transplanted trees (the "recovery" response = 1 or 0). Two types of analyses were carried out separately. The purpose of the first analysis was to study the factors "season" and "type of pruning" on Argan trees transplanted during all seasons. The second analysis concerned the effect of "preconditioning", "preconditioning/pruning type" and "season" on trees having undergone preconditioning during the summer and spring seasons. The results of these analyses are presented in Table 7, only for factors and/or combinations with statistical significance at $p<5\%$.

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Table 7. Factors and combination of factors with statistical significance (p<0,05).

Factors	Estimates						
			95% Wald Confidence Interval		Hypothesis test		
	B	Std. Error	Lower	Upper	Wald Chi Square	df	Sig.
Cut back	0.533	0.2168	0.108	0.958	6.049	1	0.014
Summer	0.498	0.1765	0.152	0.844	7.972	1	0.005
6 months watering*Cut back*Spring	-0.503	0.2109	-0.917	-0.090	5.699	1	0.017
4 months root pruning*Cut back*Spring	0.852	0.2482	0.365	1.338	11.780	1	0.001

The first analysis showed that the factors studied (season and type of pruning) had a significant effect on the recovery of transplanted Argan trees in relation to pruning, taken as a reference in the analysis (Table 7): total cat back of the branches is the most effective treatment, regardless of the season or the shape of the tree (Cut back=1.4% which is well below 5%). Regarding the "season" factor, the summer season can be considered as the most favourable time for transplantingArgan trees according to the tests carried out for all seasons, particularly when compared to the spring season (the level of significance for summer is 0.5%).

For the combined factors (season*treatment), the analysis highlights the fact that complete cut back during summer (Cut back*Summer combination) is the best compared to the other combinations but not significantly efficient as the significance level was 7.5%, higher than the 5% set up (Table 7).

The second statistical analysis showed that the factors studied (preconditioning, season and type of pruning) had a significant effect on the recovery of transplanted Argan trees: the preconditioning consisting of watering for 4 months is significantly better in comparison with the other pre-treatments (2.9% level of significance). The statistical analysis also allowed the comparison between "straight transplanting" and "preconditioning" practiced in summer and spring: the combination of watering for 6 months with trees cut back and 4-month root pruning and watering with trees cut back in the spring season have significantly higher recovery rates compared to straight transplanting during the same season. The analysis of the combination “Preconditioning*pruning type*season”revealed that the best recovery rates were as follows: “6 months watering*Cut back*Spring” with 1.7% significance level and “Root pruning and watering for 4 months*Cut back*Spring” with a high significance level (Table 7). This can be explained by the fact that the transplantation of Argan trees in spring only resulted in an overall recovery rate of 10%, half of which was due to the cut back treatment. However, preconditioning consisting of watering for 6 months and root pruning and watering for 4 months, significantly increased recovery rates during the same season.

4. Discussion

These experiments have shown that the transplantation of mature Argan trees is possible with substantial recovery rates. The main observation is that total cut back of branches promotes recovery regardless of other factors studied. Table 8 summarizes the survival rates of cut back Argan trees in comparison with the other types of pruning. Generally speaking, they exceed those of other treatments regardless of seasons and preconditioning. Even during the most unfavourable season (spring) branches cutting back ensured the highest recovery rate.

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Table 8. Summary of recovery rates (%) of cut back Argan trees in comparison with other types of pruning (April 2024).

	Trimmed or Pruned Argan trees	Cut-back Argan trees	Average
Summer 2020*	73.91	47.05	62.50
Winter 2020*	71.42	45.45	50.00
Spring 2021	50.00	06.06	10.00
Autumn 2021	72.72	55.00	61.29
Spring 2021 with preconditioning	58.62	22.44	35.89
Summer 2021 with preconditioning	23.52	17.14	19.23

Results drawn from [5] (p. 149).

It is important to emphasize that total branches cut back induces highest recovery rates if applied outside the spring season. Indeed, Argan trees cut back before their transplantation in summer, autumn, and winter had recovery rates exceeding 70% (Table 8). Even in winter when the overall recovery was relatively low, total cut back resulted in 71.42% recovery rate. Preconditioning by root pruning and watering for a few months improved recovery rates but not as much as branches cut back, without other pre-treatments. However, it would be interesting to consider combining root pruning and watering with branches cut back during the most favourable seasons in order to check whether the survival rate will be further improved. However, it is important to point out that the terrain can present 2 levels of difficulty. To correctly apply root pruning and girdling, the soil needs to be sufficiently deep and soft, which is not the case in the majority of mountain Argan groves where hard rock is generally exposed. In addition, watering requires regular water supply, which can constitute a constraint due to difficult access and additional costs due to the distance from supply sources.

The overall high recovery rates observed in summer may be explained by the fact that Argan trees go dormant during the summer season (hot and dry) [9], since in dry conditions argan trees are completely defoliated and branching is very low in the dry season compared to the wet one [10]. On the other hand, the low recovery rates observed in spring can be explained by the fact that during this season, the Argan trees resumed their growth with the reactivation of the root system [11,12]. Carrying out the transplant at this stage probably has led to the deterioration of active roots [13], especially given that the trees were uprooted with bare roots due to the rocky nature of the soil in the limestone quarry.

5. Conclusions

Due to its economic, cultural and ecological importance, the conservation of Argan trees should represent a priority for Moroccan stakeholders, whether forest managers or socio-economic development promoters. If in certain instances it is impossible to do otherwise than removing Argan trees to set up development projects, their transplantation into dedicated receptor sites should be highly recommend. This study has demonstrated that transplanting mature Argan trees is a feasible option aiming at conserving this species considered as one of the essential components of Morocco's ecological heritage. The reported results show that the transplant season and the type of pruning applied to the trees influence the recovery rate. They show that apart from spring, mature Argan trees can be transplanted at any time with more than 50 % recovery rate. In addition, if total branches cut back is applied prior to uprooting, the rate of recovery can substantially be increased. The preconditioning used in the present study - namely root pruning and watering during several months - induced recovery rates improvements, especially for spring transplantation. Nevertheless, root pruning and watering may be difficult to apply at a large scale.

It is therefore recommended to schedule transplanting during the most optimal periods: summer in priority, autumn, then winter. These seasons coincide with the Argan tree dormancy [9]. Spring should be avoided as it corresponds to the tree's most active period and therefore when it is most

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sensitive to the disturbance of its root system [11,14]. During the optimal seasons, transplanting should be combined with total branches cut back for maximum recovery rates [12]. The extensive reduction of the canopy reduces evapotranspiration, conserving the reserves for the reconstitution of the root system lost during excavation [15]. In conclusion, it should be recommended to transplant during the most suitable season that is summer and apply total branch cut back to promote recovery. It should be insisted on transplanting aftercare, consisting of regular watering and close observation.

It is important to point out that apart from the root pruning/watering preconditioning operations where root balls could be made before transplanting; the other Argan trees were transplanted bare rooted. Therefore, optimal seasons reported here and cut back allow significant recovery rates without resorting to complicated handling. Moreover, given the unpredictable and particularly restrictive climatic conditions throughout the year, the transplantation of mature Argan trees requires careful monitoring which consists of ensuring adequate watering and regular observations to identify any changes taking place afterwards. Climate change may pose a significant challenge for transplanting Argan trees as it can lead to unpredictable and extreme weather events: changes in precipitation patterns and changes in temperature regimes. These changes may require new strategies for transplantation and adaptation of transplanted trees. Furthermore, in this study, the observations only lasted 3 years and it would be useful to continue monitoring these trees over a longer period to confirm the trends about Argan growth patterns reported in this article. [16] (pp. 99–102) demonstrated that tree establishment periods significantly vary with species: red oak required 2.1 years, London plane tree 4 years, and hedge maple 5.9 years. A longer observation period will certainly enable the gathering of more comprehensive data and provide deeper insights into the long-term growth and adaptation of transplanted Argan trees.

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